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MECHANICAL AND THERMAL PROPERTIES OF HIGH-TEMPERATURE TITANIUM ALLOYS

Clifford L. Dotson
Southern Research Institute
Birmingham, Alabama 35205

Technical Documentary Report AFML-TR-67-41
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Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

NOTICES

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FOREWORD

This report was prepared by Southern Research Institute under USAF Contract No. AF 33-(615)-2266 on a program to evaluate the mechanical and thermal properties of high-temperature titanium alloys. This contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Materials Information Development". The work was administered by the Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Lt. D. C. LaGrone and Mr. D. C. Watson were the project engineers. The period covered by this report is December 1, 1964, through August 31, 1966. The manuscript was released by the author in December, 1966, for publication as an RTD Technical Report.

The mechanical-property evaluations were performed by the Metallurgy Department of Southern Research Institute under the direction of Clifford L. Dotson, Head of the Metals Evaluation Section. Assistance was provided by P. C. Jenkins, P. G. Adams, O. V. Rogers, J. K. Legg and L. F. Ferguson of the Metals Evaluation Section. The thermal property determinations were performed by D. J. Thornburgh of the Thermodynamics Section under C. M. Pyron, Head.

This technical report has been reviewed and is approved.

D. A. Shinn
Chief, Materials Information Branch
Materials Application Division
AF Materials Laboratory

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ABSTRACT

The purpose of this program was to obtain preliminary mechanical- and thermal-property design data on some of the newer titanium alloys. Three sheet alloys (Ti-5Al-5Sn-5Zr, Ti-5Al-5Sn-5Zr-1Mo-1V, and Ti-6Al-2Sn-4Zr-2Mo) and two bar alloys (Ti-5Al-5Sn-5Zr and Ti-679) were studied. Tests were performed to obtain data on the following properties: tensile, compression, bearing, shear, thermal exposure, creep, axial fatigue, fracture toughness, stress corrosion, impact, dynamic modulus, thermal conductivity, thermal expansion, and specific heat. In general these properties were determined over the temperature range from 70 to 1000° F, with most properties being measured at 70, 400, 600, 800 and 1000° F.

Results of the tests show that the new Ti-6Al-2Sn-4Zr-2Mo sheet alloy has well-balanced properties; with short-time strength at all temperatures comparable to or higher than those of other alpha-beta alloys and higher long-time strength (creep) than other alpha-beta alloys to which it was compared. The Ti-679 bar alloy also exhibited generally high strength over the temperature range at which properties were studied.

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SYMBOLS

a, b, c, β	Constants
A	Ratio of alternating to mean stress in fatigue
a	Crack length at maximum load or at pop-in in fracture-toughness tests
a_0	Half length of fatigue crack in fracture-toughness tests
B	Thickness of fracture-toughness specimen
e	Elongation
E	Dynamic modulus of elasticity
E_c	Modulus of elasticity in compression
E_t	Modulus of elasticity in tension
e/D	Ratio of distance-to-edge to bearing-hole diameter
ϵ	Strain
f	Frequency
° F	Degrees Fahrenheit
F_{cy}	Yield strength in compression at 0.2% offset
F_{bry}	Bearing yield stress
F_{bru}	Ultimate bearing stress
F_{su}	Ultimate shear stress
F_{ty}	Yield strength in tension at 0.2% offset
F_{tu}	Ultimate tensile strength
g	Gravitational constant
h_{85}	Enthalpy above reference temperature of 85° F

SYMBOLS (Cont'd)

HC	Heat capacity
k	Radius of gyration
K_c	Critical stress intensity factor associated with initiation of unstable plane-stress fracturing
K_{Ic}	Critical stress-intensity factor associated with initiation of plane-strain fracturing
K_t	Stress concentration factor
ksi	Kips (1000 pounds) per square inch
l	Length
L	Longitudinal
ν	Poisson's ratio
P	Load
ρ	Density
π	3.1416
R	Ratio of minimum stress to maximum stress in fatigue
R.A.	Reduction of area
R_c	Hardness on Rockwell C scale
σ	Gross stress at maximum load or at pop-in in fracture-toughness tests
s	Stress
T	Transverse or degrees Rankine
t	Time or thickness
w	Width of fracture-toughness specimen

MECHANICAL AND THERMAL PROPERTIES OF HIGH-TEMPERATURE TITANIUM ALLOYS

INTRODUCTION

Recent titanium-alloy development programs have resulted in several alloys that seem to have superior properties at elevated temperatures to other titanium alloys that have been commercially available in recent years. The potential of these new alloys for airframe and engine applications needs to be more thoroughly evaluated by determinations of mechanical and thermal properties over the temperature range of potential applications. Such evaluation programs will further establish the limiting time-temperature conditions and provide design data for maximum utilization of the alloys. As a step toward accomplishment of these objectives, the Air Force initiated a program at Southern Research Institute to evaluate the mechanical and thermal properties up to 1000° F for three titanium alloys in sheet form and two alloys in bar form.

SCOPE

The alloys that were selected for evaluation in sheet and bar form are shown in Table 1. The considerations involved in the selection of each of these alloys will be discussed in a subsequent section of this report.

Table 1

Alloys and Product Forms Evaluated

Bar	Sheet
Ti-5Al-5Sn-5Zr	Ti-5Al-5Sn-5Zr
Ti-679	Ti-5Al-5Sn-5Zr-1Mo-1V
	Ti-6Al-2Sn-4Zr-2Mo

The experimental program was designed for a comprehensive evaluation of properties from one heat of each alloy-product form combination and for

evaluation of the tensile properties from an additional heat of each alloy-product form. Table 2 summarizes the evaluations that were performed on the sheet and bar forms of the alloys.

Table 2

Summary of Evaluations for Sheet and Bar

Property	Product Form	Temperatures, °F
Tensile	Sheet and Bar	RT to 1000
Compression	Sheet and Bar	RT to 1000
Shear	Sheet and Bar	RT to 1000
Exposure-tensile	Sheet and Bar	600, 800, 1000
Exposure-shear	Sheet	600, 800, 1000
Over exposure-tensile	Sheet and Bar	1100, 1150, 1200
Creep	Sheet and Bar	600 to 1050[a]
Axial fatigue	Sheet and Bar	RT, 400, 800
Dynamic modulus	Sheet and Bar	RT to 1000
Fracture toughness	Sheet and Bar	RT, -110, 400
Impact	Bar	RT, 400, 600, 800
Stress corrosion	Sheet	500 to 900
Thermal conductivity	Sheet and Bar	RT to 1000
Thermal expansion	Sheet and Bar	RT to 1000
Specific heat	Sheet and Bar	RT to 1000

a. Determined at different temperatures for different alloys.

Tables 107 and 108, in Appendix III, give additional details of the mechanical-property evaluations for the sheet and bar alloys respectively. Table 109, also in Appendix III, shows a summary of the thermal properties that were determined. These tables show the orientations evaluated, additional details concerning the test conditions, and the number of specimens evaluated at different temperatures and under different conditions.

EXPERIMENTAL ALLOYS

Selection

Since the primary interest of this program was in titanium alloys for applications at high temperatures, only the super-alpha alloys were considered for the program. The original choice of alloys for evaluation was as follows:

(1) Ti-5Al-5Sn-5Zr
(2) Ti-5Al-5Sn-5Zr-1Mo-1V
(3) Ti-679

with all three alloys scheduled for evaluation in sheet form and the Ti-5Al-5Sn-5Zr and Ti-679 alloys additionally scheduled for evaluation in bar form.

Although the Ti-5Al-5Sn-5Zr alloy has been evaluated in previous investigations, there was a twofold purpose for including this alloy in the present program. First, since the alloy is established as a good high-temperature alloy, inclusion of the alloy in this program provided reference properties against which the properties of the new alloys could be compared in the same product form and under the same experimental conditions. Second, although data have been obtained on the tensile and creep properties of the Ti-5Al-5Sn-5Zr alloy, many of the other properties that were studied in this program had not been determined for the alloy.

The third sheet alloy originally scheduled for evaluation was the Ti-679 alloy. This alloy was introduced by Imperial Metal Industries, Ltd., in Britain as IMI 679. Its nominal composition is 2.2% Al, 11% Sn, 5% Zr, 1% Mo and 0.2% Si. The microstructure contains a dispersion of titanium-silicide particles after solution annealing at 1650° F and aging at 930° F, which is thought to contribute to the high strength of the alloy. The principal use of the alloy in Britain has been for forgings. Titanium Metals Corporation of America (TMCA) obtained a license for producing the alloy in this country and have continued its development. Preliminary data showed that the alloy also had good high-temperature strength in sheet form, which was the primary reason for including it in the original selection of sheet alloys for this program. Additional data that became available at the time the alloys were being selected showed that the Ti-679 alloy had relatively poor fracture toughness in sheet form. For this reason the Ti-679 sheet was eliminated from the program. The alloy selected to replace the sheet form of Ti-679 was a very new composition which TMCA suggested after a preliminary evaluation. The nominal composition of the replacement alloy was Ti-6Al-2Sn-4Zr-2Mo. The preliminary data showed that the Ti-6Al-2Sn-4Zr-2Mo had comparable tensile strength to the Ti-5Al-5Sn-5Zr-1Mo-1V alloy from room temperature to 1000° F which, at all temperatures, is significantly higher than the tensile

strength of the basic Ti-5Al-5Sn-5Zr composition. Also, from preliminary tests the Ti-6Al-2Sn-4Zr-2Mo composition seemed to have creep strength comparable to the high creep strength of the Ti-5Al-5Sn-5Zr alloy. Tensile tests at room temperature on specimens which were exposed at 800, 1000, and 1100° F for 150 hr in creep tests in the early evaluations suggested that the alloy had good thermal stability.

In the original program schedule, experimental materials of each alloy and product form were to be procured from two producers. However, most of the alloys were not available from more than one producer except from small ingots that would have to be produced especially for the program. After considering the cost for these special heats and the undesirability of using material from small ingots in the program, we recommended that the material representing two heats of each alloy-form be procured from a single producer, Titanium Metals Corporation of America.

Processing

The processing sequence for each experimental material is summarized in the following paragraphs.

A. Ti-5Al-5Sn-5Zr Sheet (Heats D-8060 and D-1793)

1. Ingots were press forged 16-in. square from 2050° F and to 3 x 12-in. sheet bars from 1950° F. The slabs were conditioned and ultrasonically inspected.

2. Sheet bars were cut and rolled to intermediate size from 1880 - 1900° F, descaled, acid pickled, and the surfaces conditioned to remove defects.

3. The material was finish rolled from 1750° F, descaled and acid pickled, anneal-flattened at 1350° F (8 hr), and rough ground.

4. Sheets were final annealed at 1650° F (1/2 hr) A.C., descaled, finish ground, acid pickled, and tested as 0.040-in. gage.

B. Ti-5Al-5Sn-5Zr-1Mo-1V Sheet (Heats V-2957 and V-1991)

1. Ingots were press forged to 7 x 11-inch sections from 2050° F and to 3 x 12-inch slabs from 1950° F, conditioned, and ultrasonically inspected.

2. Sheet bars were cut and rolled to intermediate size from 1860° F, descaled, acid pickled, and the surfaces conditioned to remove defects.

3. The material was finish rolled from 1700° F, descaled and acid pickled, anneal-flattened at 1350° F (8 hr), and rough ground.

4. Sheets were annealed at 1550° F (1/2 hr) A.C., descaled and rough ground, annealed at 1400° F, (1/4 hr) A.C., descaled, finish ground, acid pickled, and tested at 0.040-inch gage.

C. <u>Ti-6Al-2Sn-4Zr-2Mo Sheet</u> (Heats V-3016 and V-3076)

1. Ingots were press forged to 7 x 11-inch section (V-3016) or directly to 3 x 12-inch slab (V-3076) from 2050° F, and in the case of V-3016 to 3 x 12-inch slab from 1950° F, conditioned, and ultrasonically inspected.

2. Sheet bars were cut and rolled to intermediate size from 1790 - 1800° F, descaled, acid pickled, and the surfaces conditioned to remove defects.

3. The material was finish rolled from 1750° F, descaled and acid pickled, anneal-flattened at 1350° F (8 hr), and rough ground.

4. Sheets were annealed at 1650° F (1/2 hr) A.C., descaled and rough ground, annealed at 1450° F (1/4 hr), A. C., descaled, finish ground, acid pickled, and tested at 0.040-inch gage.

D. <u>Ti-5Al-5Sn-5Zr Bar</u> (Heats D-8060 and D-1793)

1. Ingots were press forged 16-inch square from 2050° F, and to 4-inch square billets from 1950° F.

2. Billets were thoroughly conditioned and ultrasonically inspected.

3. Billets (4-inch square) re-cogged to 2-1/2-inch square from 1950° F (2" x 6" x 16" pieces of D-1793 pressed slab were hammer forged to 2-1/2-inch square from 1950° F), conditioned, rolled to 1/2 x 1-1/8-inch bars from 1925° F, and descaled.

4. Rolled bars were annealed-straightened at 1650° F, 2 hr, A.C., descaled, and tested.

E. <u>Ti-679 Bar</u> (Heats D-7274 and D-8427)

1. Billet stock (D-7274 - 8" round and D-8427 - 12" octagon) were press forged to 4-inch square billets from 1675° F, conditioned, and ultrasonically inspected.

2. Billets (4-inch square) were re-cogged to 2-1/2-inch square from 1675 - 1700° F, conditioned, rolled to 1/2 x 1-1/8-inch bars from 1675° F, and descaled.

3. Rolled bars were annealed-straightened at 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C., descaled, and tested.

Heat Treatment

The selection of the final heat treating cycle for each sheet and bar alloy was based primarily on recommendations by TMCA. These recommendations were made on the basis of production experience with some of the alloys and on preliminary laboratory data for other alloys. Table 3 shows a summary of the final heat treatments for all the experimental materials.

Table 3

Summary of Heat Treatments for the Experimental Alloys

Alloy	Form	Heat Treatment
Ti-5Al-5Sn-5Zr	Sheet	1650° F, 1/2 Hr, A.C.
Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	1550° F, 1/2 Hr, A.C. + 1400° F, 1/4 Hr, A.C.
Ti-6Al-2Sn-4Zr-2Mo	Sheet	1650° F, 1/2 Hr, A.C. + 1450° F, 1/4 Hr, A.C.
Ti-5Al-5Sn-5Zr	Bar	1650° F, 2 Hr, A.C.
Ti-679	Bar	1650° F, 2 Hr, A.C. + 930° F

As this table shows, the all-alpha alloy, Ti-5Al-5Sn-5Zr, was evaluated in the solution-annealed condition. Of the alpha-beta alloys, the two sheet materials were solution-annealed and then held for 1/4 hr at 1400° F (Ti-5Al-5Sn-5Zr-1Mo-1V) or 1450° F (Ti-6Al-2Sn-4Zr-2Mo). This final treatment was to simulate the hot-sizing operation that is usually used in forming titanium-alloy-sheet-parts to achieve the final dimensions of the part. It is recognized that higher strength could be achieved by aging the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alloys at about 1100° F after either the solution-anneal or after the hot-sizing thermal treatments (1/4 hr at 1400-1450° F), as may be seen from preliminary data supplied by TMCA[1] and shown in Figures 1 and 2. The two alpha-beta alloy sheet materials were evaluated in the annealed + hot sizing treated condition because it was anticipated that this would be the condition in which most of the sheet would be used.

[1] Superscript figures indicate references.

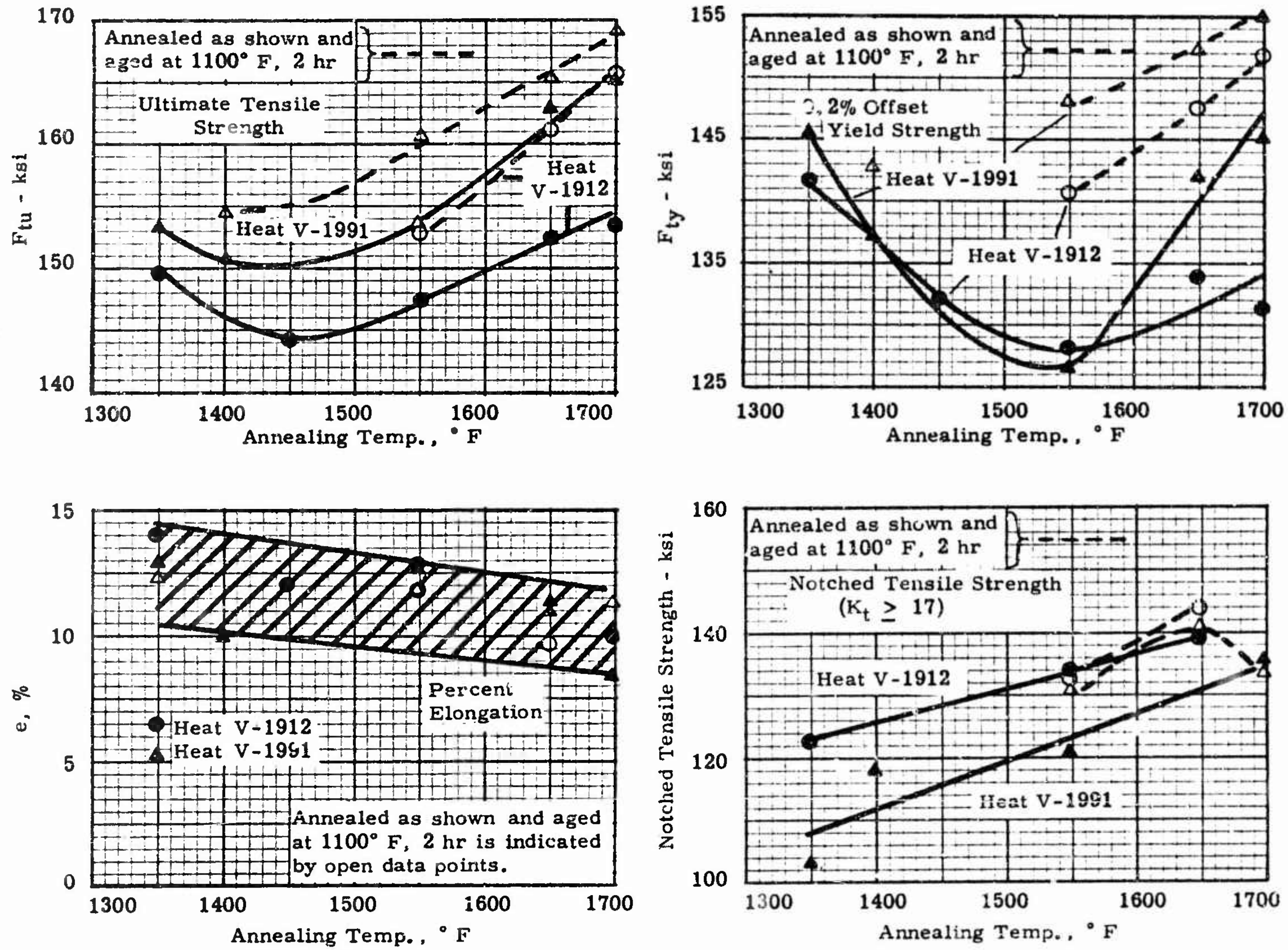


Figure 1. The Effect of Annealing Temperature on the Room Temperature Tensile Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet from Two Heats. Samples Annealed 1/2 hr at Temperatures Shown and Air Cooled. All Specimens from the Longitudinal Orientation.

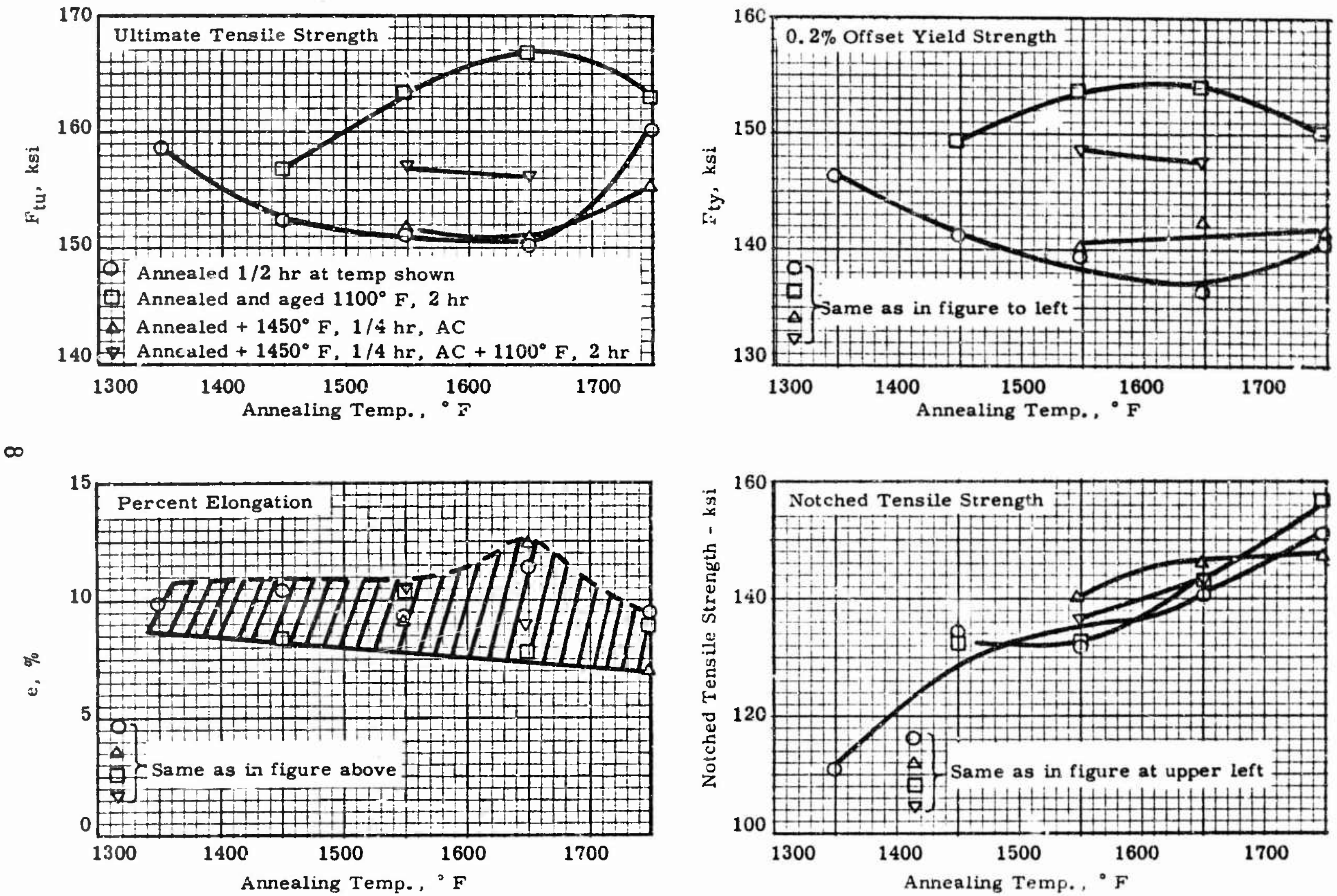


Figure 2. The Effect of Annealing Temperature on the Room-Temperature Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet. All Specimens from the Longitudinal Orientation.

The Ti-679 alloy was evaluated in the solution-treated-plus-aged condition which is normally used for the alloy.

Properties of As-Received Materials

The quantity and identification of the sheet and bar alloys that were procured for the program is shown in Table 4. As mentioned previously, material from two heats was procured for each sheet and bar alloy in sufficient quantities for the determination of all properties from one heat (A) and for determination of only the tensile properties from the secondary heat (B). The Ti-5Al-5Sn-5Zr alloy sheet and bar were from the same heat. Table 5 shows the composition (furnished by TMCA) for all the experimental alloys.

The results of tensile tests performed by TMCA on each alloy are given in Table 6. The strength and ductility properties as given in this table for each heat are in reasonable agreement with results we obtained in tensile tests at room temperature.

The hardness of each bar and sheet were checked, for which results are given in Tables 7 and 8. On the bar alloys the hardness was checked at one end of each as-received length of the bars, and on the sheets the hardness was checked at locations shown in Table 8. The hardness of the bar and sheet were found to be uniform within normal limits of variation. In addition to the hardness measurements, the microstructures were examined of each as-received length of the bar materials and each sheet at the five locations where hardness measurements were made. Figures 3 and 4 show typical microstructures for each bar and sheet alloy. The microstructure was found to be uniform at all locations for both product forms.

Table 4

Quantity and Identification of Materials Procured for the Program

Item No.	Primary or Secondary Heat[a]	Description	Heat No.
1	A	Ti-5Al-5Sn-5Zr, 2 pcs 36 in. x 96 in. x 0.040 in. sheet	D-8060
2	B	Ti-5Al-5Sn-5Zr, 1 pc, 36 in. x 48 in. x 0.040 in. sheet	D-1793
3	A	Ti-5Al-5Sn-5Zr-1Mo-1V, 2 pcs, 36 in. x 96 in. x 0.040 in. sheet	V-2957
4	B	Ti-5Al-5Sn-5Zr-1Mo-1V, 1 pc 36 in. x 48 in. x 0.040 in. sheet	V-1991
5	A	Ti-6Al-2Sn-4Zr-2Mo, 2 pcs. 36 in. x 96 in. x 0.040 in. sheet	V-3016
6	B	Ti-6Al-2Sn-4Zr-2Mo, 1 pc, 36 in. x 48 in. x 0.040 in. sheet	V-3076
7	A	Ti-5Al-5Sn-5Zr, 70 lin ft, 1/2 in. x 1-1/8 in. bar	D-8060
8	B	Ti-5Al-5Sn-5Zr, 16 lin ft, 1/2 in. x 1-1/8 in. bar	D-1793
9	A	Ti-679, 70 lin ft, 1/2 in. x 1-1/8 in. bar	D-7274
10	B	Ti-679, 16 lin ft, 1/2 in. x 1-1/8 in. bar	D-8427

[a] A and B denote primary heat (all evaluations) and secondary heat (tensile evaluations only) respectively of each alloy.

Table 5

Certified Chemical Analysis of Materials[a, b]

Item	Alloy	Form	Heat	C	Fe	Al	V	Mo	Zr	Sn	Si	O	H	N
1	Ti-5Al-5Sn-5Zr	Sheet	D-8060	0.025	0.05	5.3	-	-	5.3	5.1	-	0.10	0.005	0.011
2	Ti-5Al-5Sn-5Zr	Sheet	D-1793	0.027	0.04	5.0	-	-	4.9	4.8	-	0.06	0.007	0.012
3	Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	V-2957	0.031	0.12	4.9	1.0	1.0	4.7	4.7	-	0.08	0.012	0.012
4	Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	V-1991	0.023	0.11	5.2	0.98	1.1	4.8	5.0	-	0.08	0.007	0.010
5	Ti-6Al-2Sn-4Zr-2Mo	Sheet	V-3016	0.022	0.05	6.2	-	2.0	4.2	2.0	-	0.08	0.005	0.006
6	Ti-6Al-2Sn-4Zr-2Mo	Sheet	V-3076	0.025	0.05	6.0	-	2.1	4.1	2.2	-	-	-	0.010
7	Ti-5Al-5Sn-5Zr	Bar	D-8060	0.025	0.05	5.3	-	-	5.3	5.1	-	0.10	0.010	0.011
8	Ti-5Al-5Sn-5Zr	Bar	D-1793	0.027	0.04	5.0	-	-	4.9	4.8	-	0.060	0.010	0.012
9	Ti-679	Bar	D-7274	0.023	0.06	2.4	-	0.97	4.7	10.8	0.23	0.127	0.007	0.012
10	Ti-679	Bar	D-8427	0.023	0.06	2.0	-	1.0	4.6	11.2	0.24	0.123	0.005	0.008

a Certified by TMCA.
b Analytical results given as percent by weight.

Table 6

Room-Temperature Tensile Data Supplied by TMCA for the Experimental Materials

Item	Alloy	Form	Heat	Direction	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	Hardness[b] Rc
1[a]	Ti-5Al-5Sn-5Zr	Sheet	D-8060	L	113.3	126.6	16.5	-	33.3
				T	114.0	124.6	16.7	-	-
2	Ti-5Al-5Sn-5Zr	Sheet	D-1793	L	113.1	124.1	16.0	-	31.0
				T	114.9	120.2	17.5	-	-
3[a]	Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	V-2957	L	137.8	151.5	10.0	-	35.0
				T	140.5	150.6	11.5	-	-
4	Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	V-1991	L	150.7	155.5	13.0	-	33.3
				T	133.8	155.6	11.5	-	-
5[a]	Ti-6Al-2Sn-4Zr-2Mo	Sheet	V-3016	L	138.5	146.2	12.3	-	34.3
				T	137.5	145.3	12.0	-	-
6	Ti-6Al-2Sn-4Zr-2Mo	Sheet	V-3076	L	137.5	150.7	13.0	-	34.3
				T	133.5	145.9	10.0	-	-
7	Ti-5Al-5Sn-5Zr	Bar	D-8060	L	121.0	131.0	18.0	41	31.5
8	Ti-5Al-5Sn-5Zr	Bar	D-1793	L	117.5	125.0	15.0	37	30.0
9	Ti-679	Bar	D-7274	L	136.5	149.0	18.0	39	36.1
10	Ti-679	Bar	D-8427	L	127.0	142.0	15.0	32	36.0

a. Average of two values reported for both longitudinal and transverse orientations.
b. Determined by Southern Research Institute.

Table 7

Results of Hardness Tests on Bar Materials as Received

Alloy	Heat No.	Rockwell C Hardness[a] Bar Number 1	2	3	4	5	6	7	Avg.
Ti-5Al-5Sn-5Zr	D-8060	32.0	31.0	31.5	31.1	31.8	32.0	31.8	31.5
Ti-5Al-5Sn-5Zr	D-1793	30.0	-	-	-	-	-	-	30.0
Ti-679	D-7274	36.1	36.0	35.6	35.0	34.0	36.3	36.2	35.6
Ti-679	D-8427	36.0	-	-	-	-	-	-	36.0

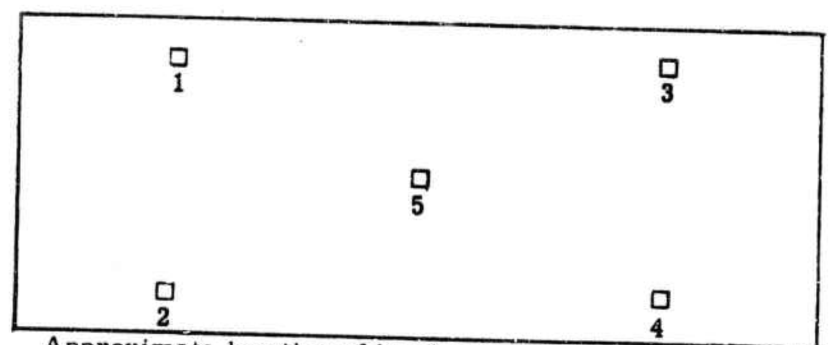
a. Average of three hardness readings at each location.

Table 8

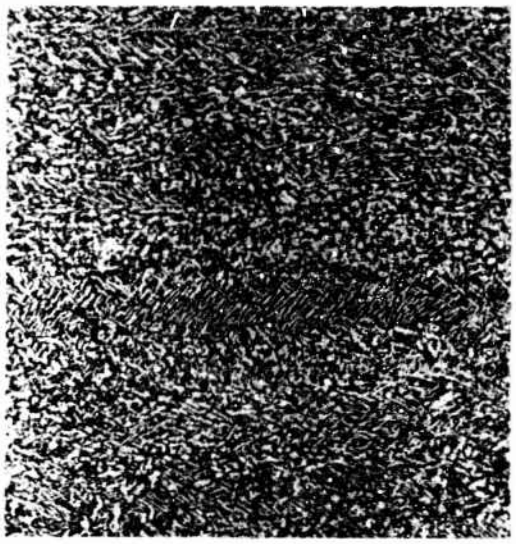
Results of Hardness Tests on Sheet Materials as Received

Alloy	Heat No.	Sheet No.	Rockwell C Hardness[a] Location in Sheet 1	2	3	4	5	Avg
Ti-5Al-5Sn-5Zr	D-8060	1	34.0	34.0	34.0	33.0	34.0	33.8
		2	32.5	32.5	33.0	34.0	32.5	32.9
Ti-5Al-5Sn-5Zr	D-1793	1	31.0	31.0	30.6	31.3	31.0	31.0
Ti-5Al-5Sn-5Zr-1Mo-1V	V-2957	1	35.0	35.0	35.0	35.0	35.0	35.0
		2	35.0	35.0	35.0	35.0	34.0	34.8
Ti-5Al-5Sn-5Zr-1Mo-1V	V-1991	1	33.3	33.3	33.3	33.3	33.4	33.3
Ti-6Al-2Sn-4Zr-2Mo	V-3016	1	35.0	35.0	34.0	35.0	34.0	34.6
		2	34.5	33.0	34.0	34.5	34.5	34.1
Ti-6Al-2Sn-4Zr-2Mo	V-3076	1	35.0	34.5	34.0	33.5	34.5	34.3

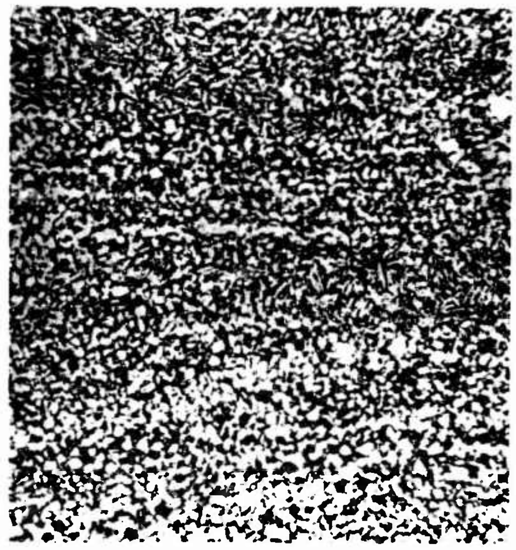
a. Average of three readings at each location on 30-N scale converted to Rc.



Approximate location of hardness specimens in sheet.



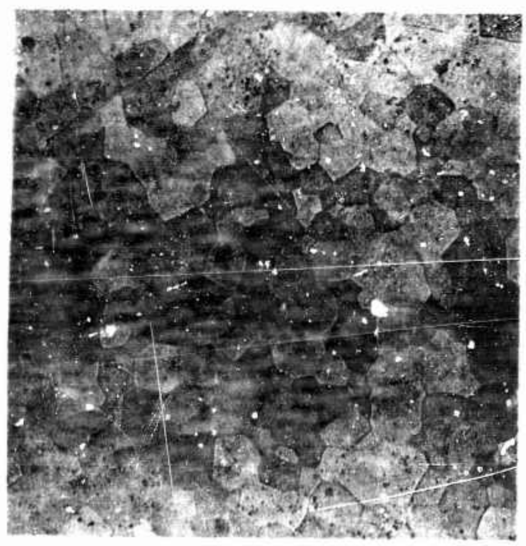
Heat No. D-7274



Heat No. D-8427

Ti-679 Alloy

Heat No. D-8060



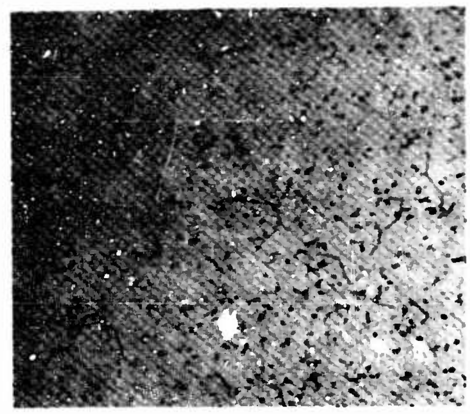
Heat No. D-1793

Ti-5Al-5Sn-5Zr Alloy

Figure 3. Microstructures of the Two Bar Alloys.

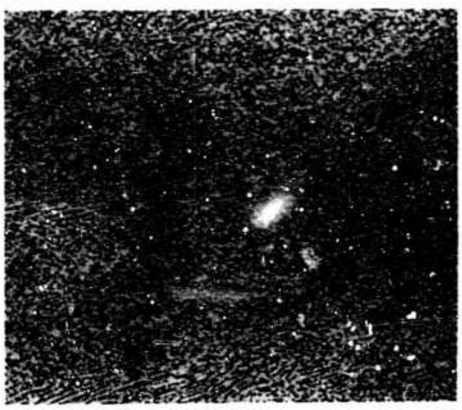
Etchant: 1 ml HF + 2 ml HNO_3 + 98 ml H_2O
Magnification: 250X

Heat No. D-8060

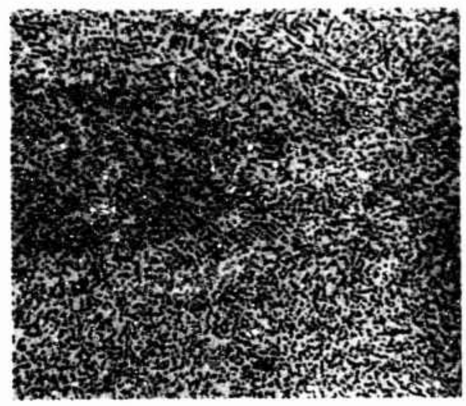


Heat No. D-1793

Ti-5Al-5Sn-5Zr Alloy



Heat No. V-2957



Heat No. V-1991

Ti-5Al-5Sn-5Zr-1Mo-1V Alloy

Heat No. V-3016

Heat No. V-3076

Ti-6Al-2Sn-4Zr-2Mo Alloy

Figure 4. Microstructure of the Three Sheet Alloys.
Etchant: 1 ml HF + 2 ml HNO_3 + 98 ml H_2O
Magnification: 250X

EQUIPMENT AND PROCEDURES

Tensile, Compression, Bearing and Shear

Except for the tensile tests on notched specimens, all the tensile, compression, bearing and shear evaluations as well as tensile tests on thermal-exposure, stress-corrosion, and fracture-toughness specimens were performed on 120,000-psi capacity universal testing machines. These machines have different load ranges from 0 - 3000 up to their full capacity. The calibration of each load range is checked and, if necessary, adjusted to bring the indicated error to within 1% on a 12-month-interval schedule. Both machines are equipped with differential-transformer strain sensing and recording equipment capable of strain magnifications of 100X to 1000X, depending upon the extensometer used with the system. Extensometers were used to record load-strain curves in the tensile tests and load-deformation curves in the bearing tests. In the elevated-temperature tensile tests the extensometers were used with a frame which extended into the furnace and was attached to the gage points of the specimen.

A split muffle furnace, which was heated by Nichrome elements, was used for all of the elevated-temperature tensile, bearing, and shear evaluations. Because of their size, the bar and sheet fracture-toughness specimens tested at 400 F were heated by quartz-tube, tungsten-element radiation lamps. The fracture-toughness specimens tested at -110° F were cooled in a cryostat by gaseous nitrogen which was cooled by passage through a copper coil that was submerged in liquid nitrogen. The flow of gaseous nitrogen was regulated to maintain the specimen at -110° F. Chromel-alumel thermocouples and a direct-reading milivolt potentiometer were used to measure and control the temperature of the specimens at all elevated and low temperatures. Specimens were heated to temperature in approximately 15 min and held at temperature 15 min before starting the tests. In these tests the indicated temperature was normally maintained within 5° F of the nominal test temperature.

Figures 5 - 8 show the specimens that were used for the tensile, compression, bearing, and shear evaluations respectively. Except for the compression and bearing tests and the shear tests on the bar alloys, conventional pin-and-clevis or threaded grips were used for sheet and bar specimens.

The notched tensile tests, which were not scheduled in the original scope of the program, were performed by the Air Force Materials Laboratory to obtain data for use in the constant life fatigue diagrams. All of these tests except the elevated-temperature tests on the bar alloys, were performed with a Model TT-C Instron testing machine. A Baldwin FGT machine was used to test the bar samples at elevated temperatures. During the tests the crosshead rate was controlled at 0.02 in./min. The temperature of the notched

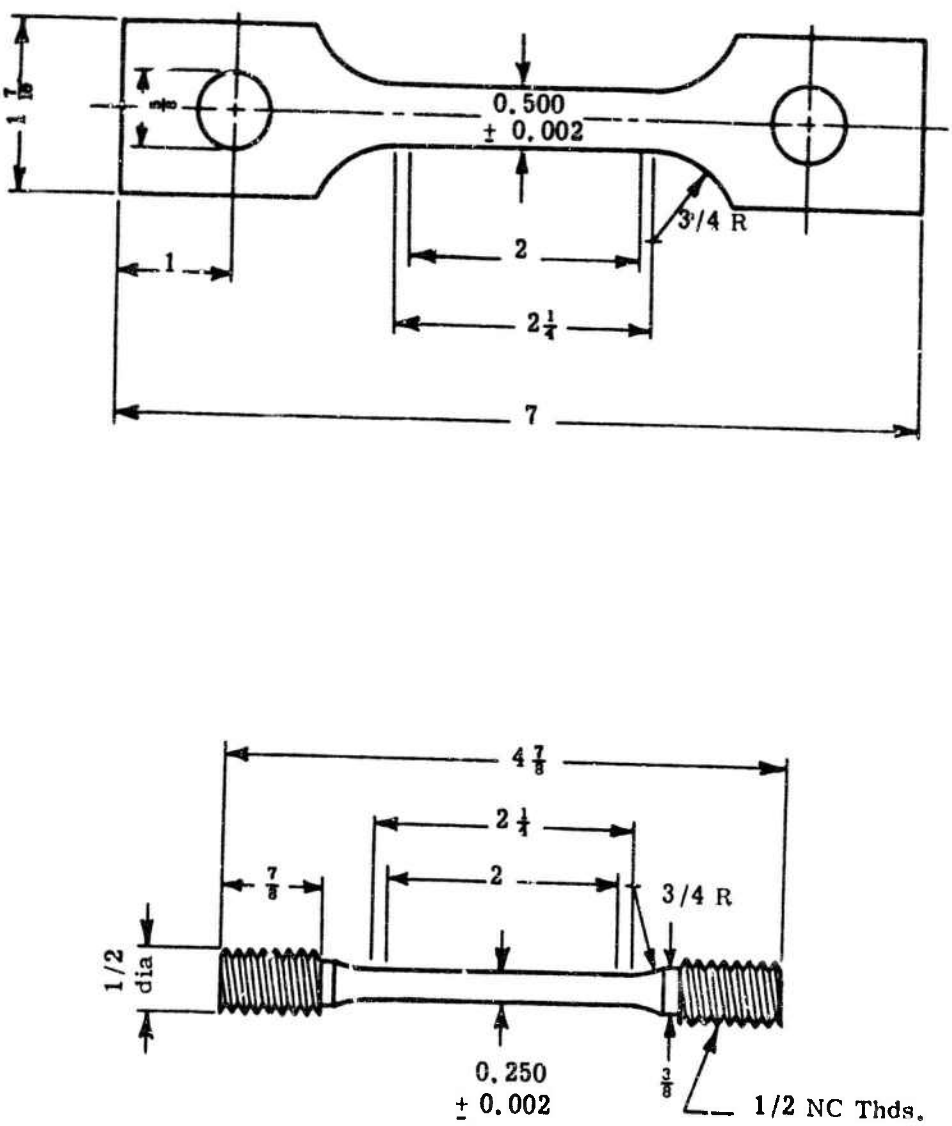


Figure 5. Specimens for Tensile, Creep, Exposure-Tensile and Stress-Corrosion (sheet only) for Sheet and Bar Materials.

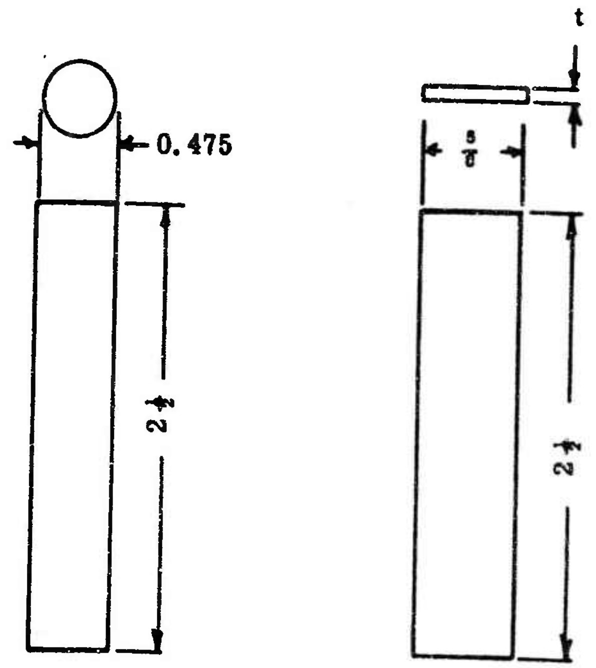
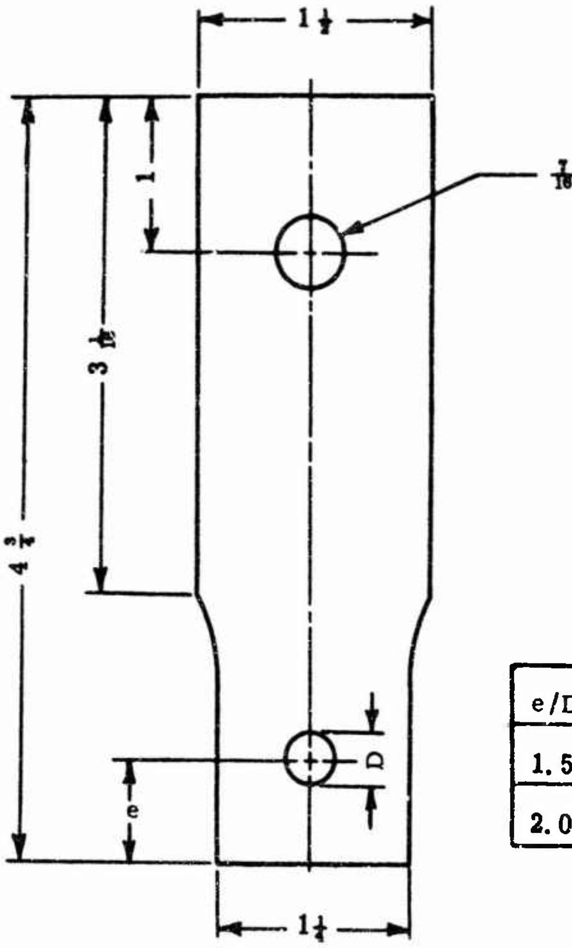


Figure 6. Compression Specimens for Sheet and Bar Materials.



e/D	e	D
1.5	0.280	0.187
2.0	0.375	0.187

Figure 7. Bearing Specimen.

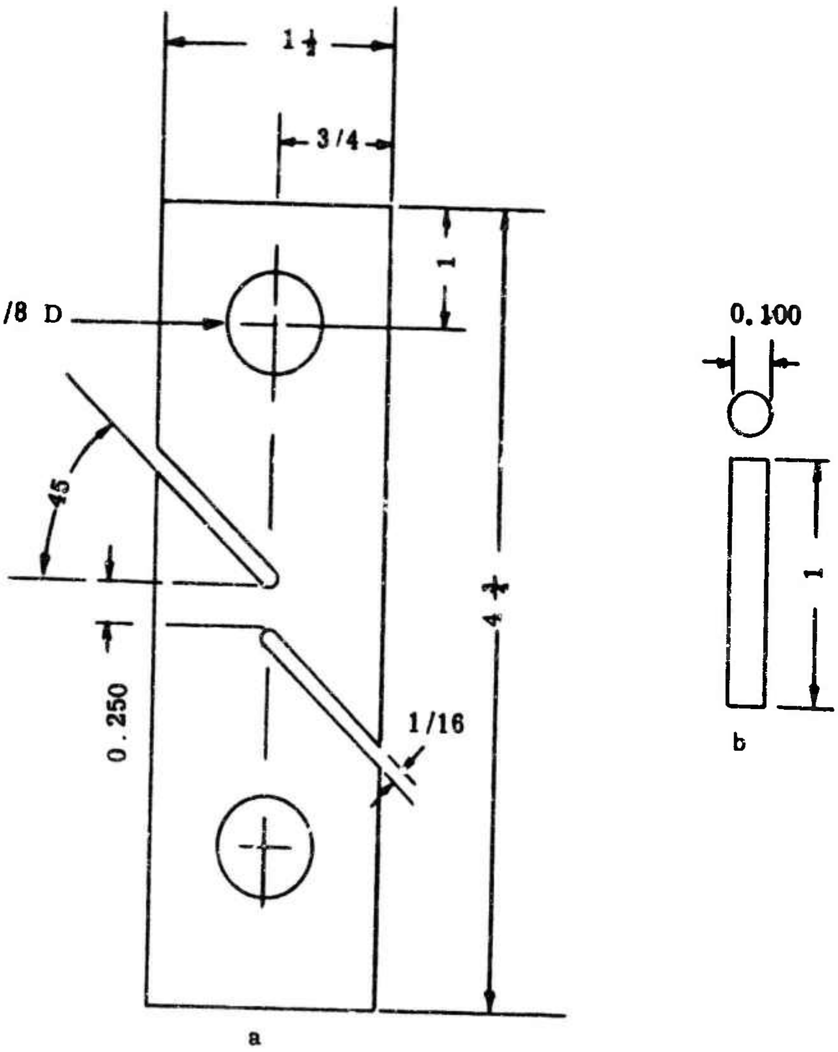


Figure 8. Shear Specimen for Sheet (a) and Bar (b) Materials

specimens was measured by calibrated chromel-alumel thermocouples which were wired to the specimen at the notch and at positions 0.5 in. above and below the notch. The maximum temperature gradient measured in these tests was less than ± 3° F of the nominal control temperature. Smooth tensile specimens, shown in Figure 5, were notched for these tests to produce a stress concentration factor, $K_t = 3$. The sheet specimens were notched 45° to a minimum width of 0.375 in. and root radius of 0.025 in. The bar specimens were notched 45° to a minimum diameter of 0.187 in. and a root radius of 0.010 in.

Special fixtures were used for the compression and bearing tests and for the shear tests on the bar alloys as shown in Figures 9 - 12. The subpress for the compression tests on sheet and bar specimens, shown in Figures 9 and 10, was designed to the requirements of ASTM Specification E 9-61. The specimen is deformed by round (for bar) or flat (for sheet) platens th t extend into the nickel-support blocks which provide bending restraint for the specimens and serve to conduct heat to the specimen from the cartridge heaters. Strain was sensed at the platens by opposite strain-gage extensometers that were located outside the furnace. The signal from the extensometer was recorded against that from a strain-gage load cell (after suitable amplification) on an X-Y recorder to obtain the usual load-deformation curve. The bearing fixture, which meets the general requirements of ASTM E 238-64T, is shown in Figure 11. Deformation of the bearing hole was sensed by the differential-transformer extensometer and recorded against load with a conventional autographic recorder. The special fixture for the shear tests on specimens of the bar alloys is shown in Figure 12. With this fixture, the specimen is sheared by tool-steel inserts in the fixture.

Tensile tests were performed at a strain rate of approximately 0.005 min^{-1} to about 0.6%-offset and at 0.05 min^{-1} to failure. In the compression tests, specimens were strained at approximately 0.005 min^{-1} to 0.6%-offset, at which point the tests were discontinued. Bearing and shear tests were performed at a crosshead rate of approximately 0.005 in. min^{-1}.

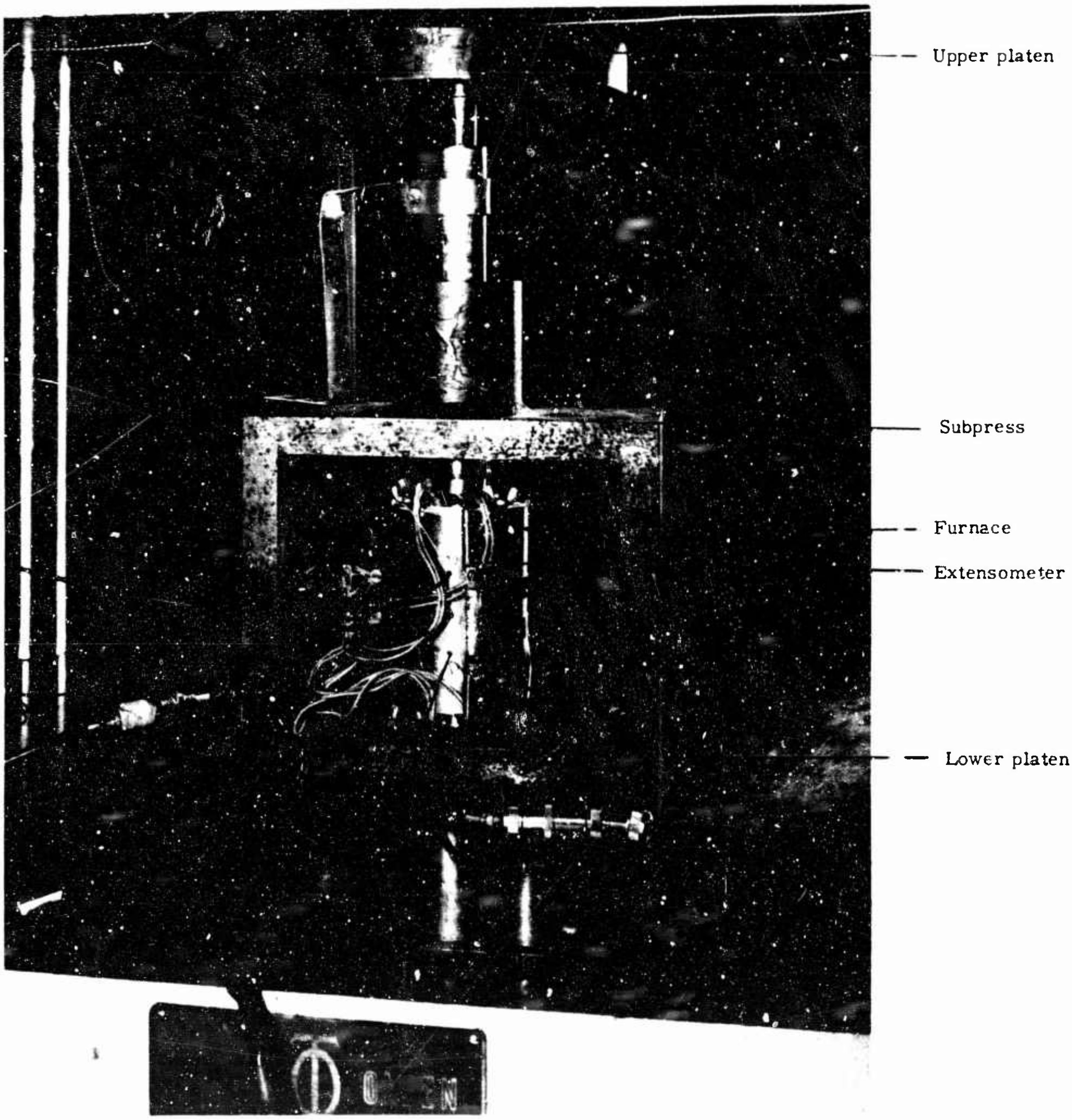


Figure 9. Compression-Test Fixture

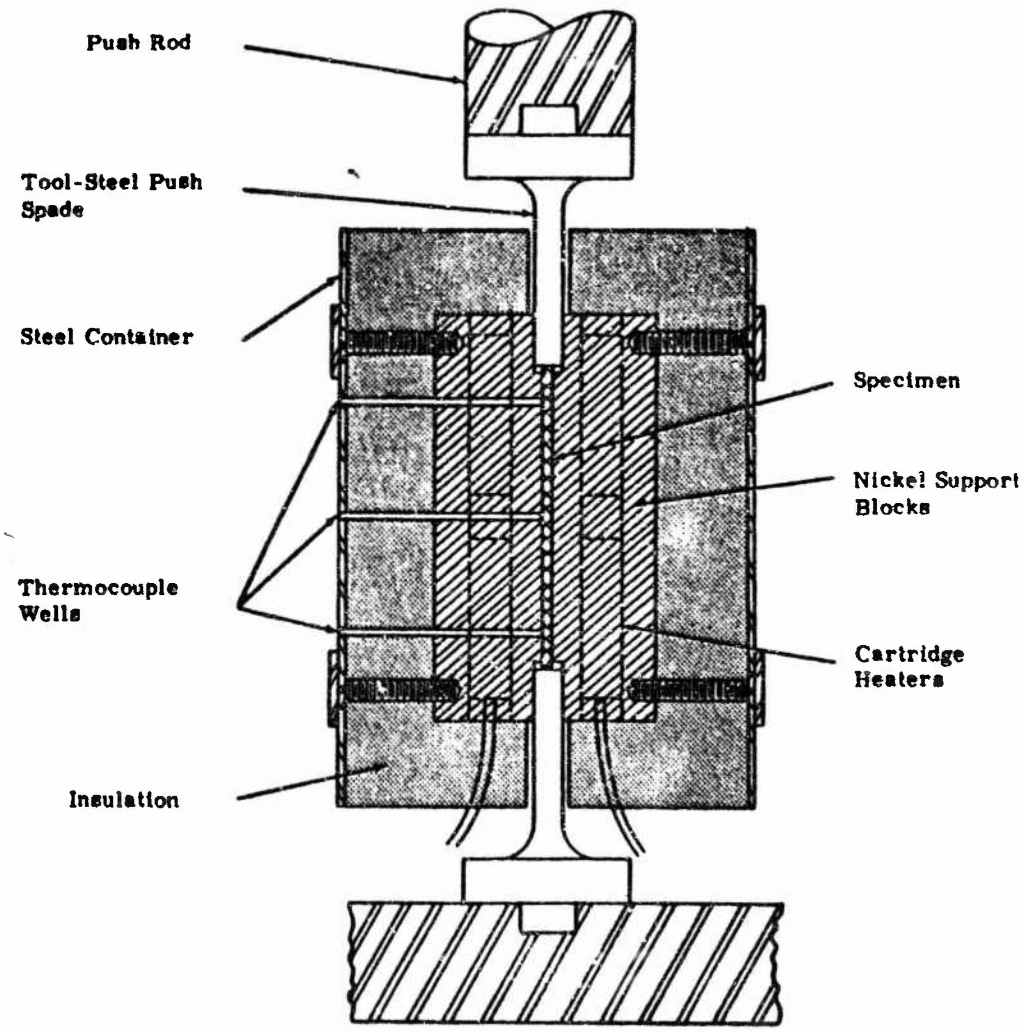


Figure 10. Cross-Section of Compression Furnace and Fixture.

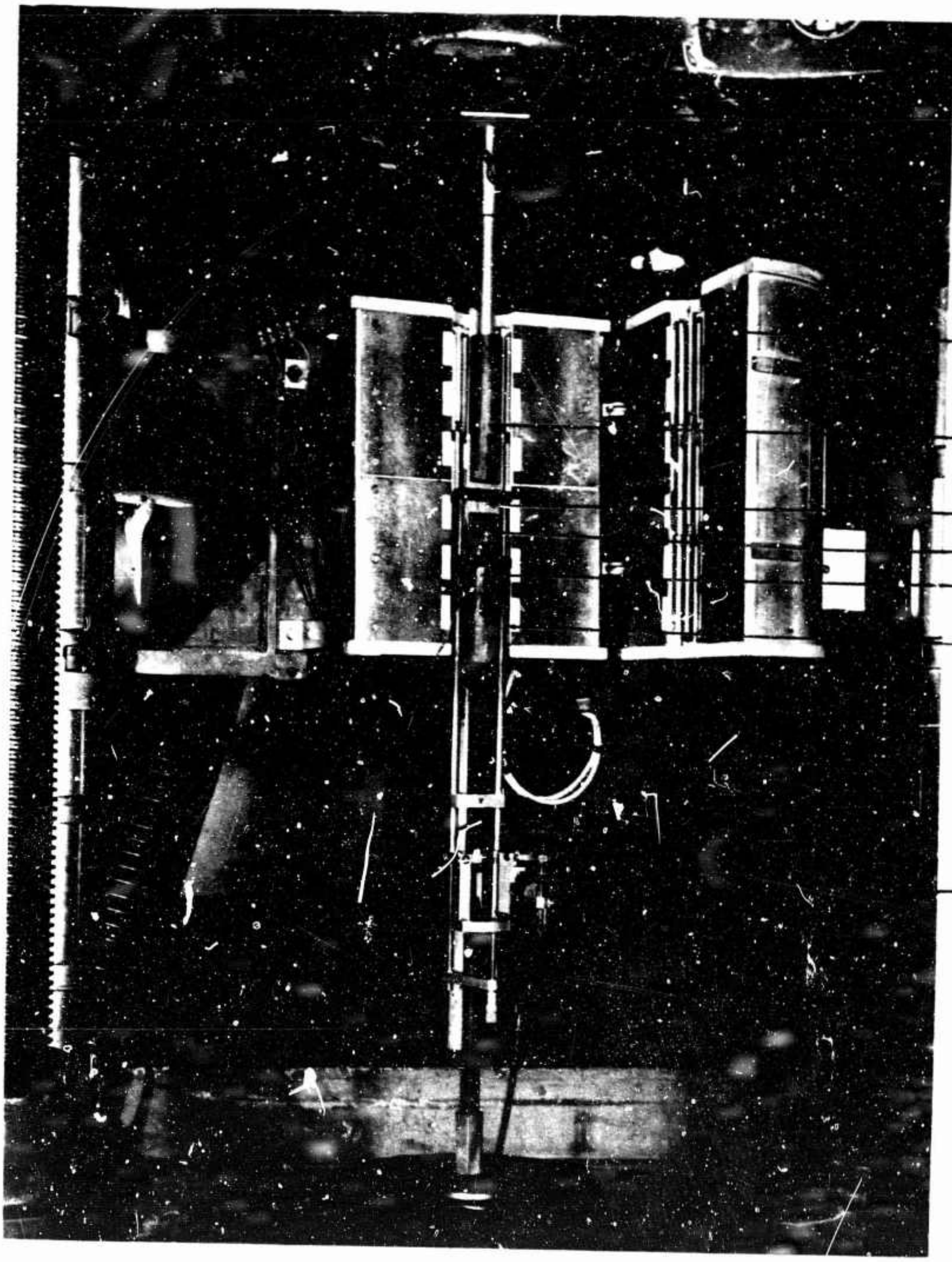


Figure 11. Apparatus for Bearing Tests

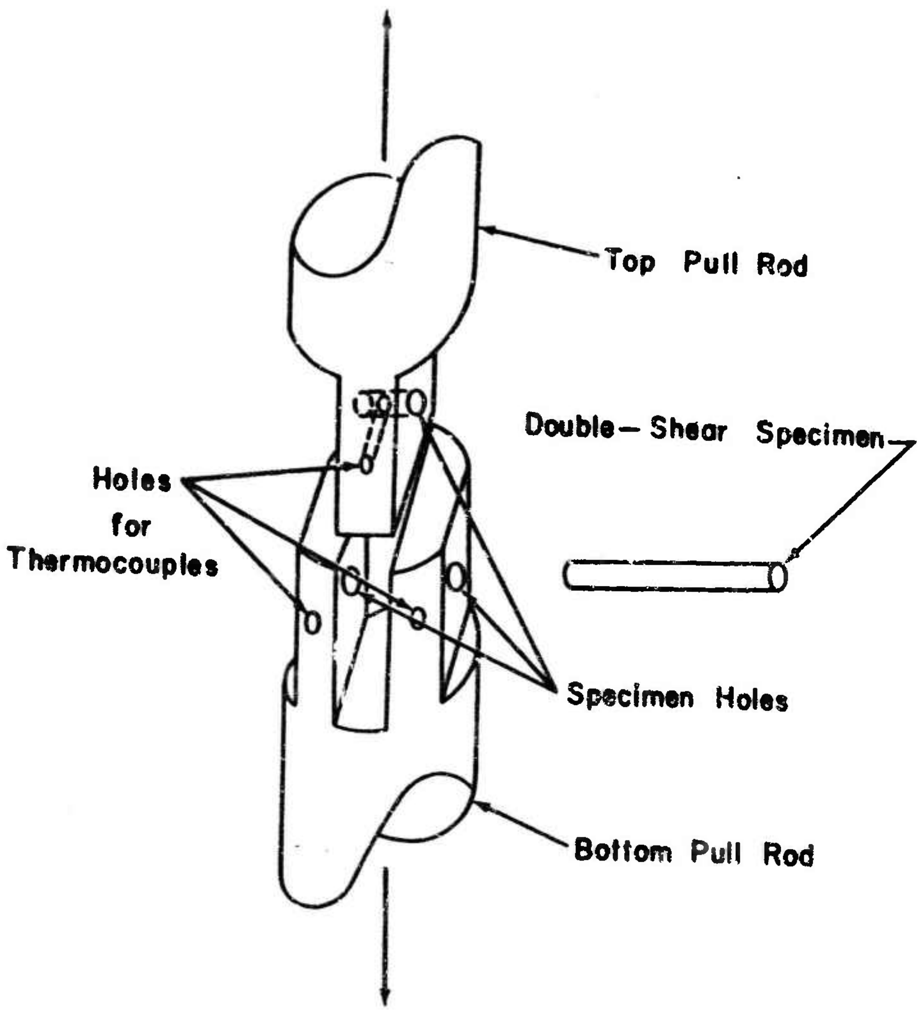


Figure 12. Shear-Test Fixture for Bar Materials

Creep

The creep tests were performed with Satec creep machines of 6000, 12000, or 16000 lb capacity. These machines are equipped with 3-zone muffle furnaces by means of which temperature gradients in the specimens can be minimized. Chromel-alumel thermocouples were used to control and monitor the temperature of the specimens. Besides the control thermocouple for the furnace, monitoring couples were attached at top, middle, and bottom locations of the specimen gage length. A direct reading milivolt potentiometer was used to measure temperatures periodically during each test. Specimens were heated to temperature and equalized in 2 to hr before application of load. The indicated temperature was normally maintained within 5° F of the nominal test temperature. In all tests of 100-hr or longer anticipated duration, and in all tests on sheet specimens, strain was measured either by platinum-strip extensometers and a 50X filar microscope or by an extensometer frame and a dial gage. When the anticipated duration of tests on bar-alloy specimens was less than 100 hr, or when the anticipated deformation was large, strain was sensed from the pull rods with dial gages.

Axial Fatigue

Axial fatigue apparatus of the resonating beam type was used in the evaluation of the fatigue properties and to fatigue crack the fracture-toughness specimens from the sheet alloys. Figure 13 is a schematic drawing of the equipment and Figure 14 shows a general view of the two machines, and related apparatus, used in the program. With this equipment a sinusoidal cyclic stress is applied to the specimen by the adjustable eccentric flywheel that is attached to one side of the resonating H-frame. The amplitude of the cyclic stress is controlled by the speed and eccentricity of the flywheel. The mean axial load is applied by the load bar and springs located near the top of the resonating frame. A strain-gage load cell, which is in series with the specimen, is used to measure the mean and cyclic stresses. A nul-balance potentiometric instrument is used in conjunction with the load cell to set the mean stress, and an oscilloscope is used to set and monitor the alternating stress.

The equipment can be used to obtain fatigue data under most mean-to-alternating-stress relationships that are of interest to designers. Completely reversed loading ($A = \infty$ or $R = -1$)[a] can be achieved or combined stress loading can be achieved under conditions where the magnitude of the alternating load does not exceed the mean load ($A = 1$ or less, or $R = 0$ or greater)[a].

a $A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$ $R = \frac{\text{Minimum Stress}}{\text{Maximum Stress}}$

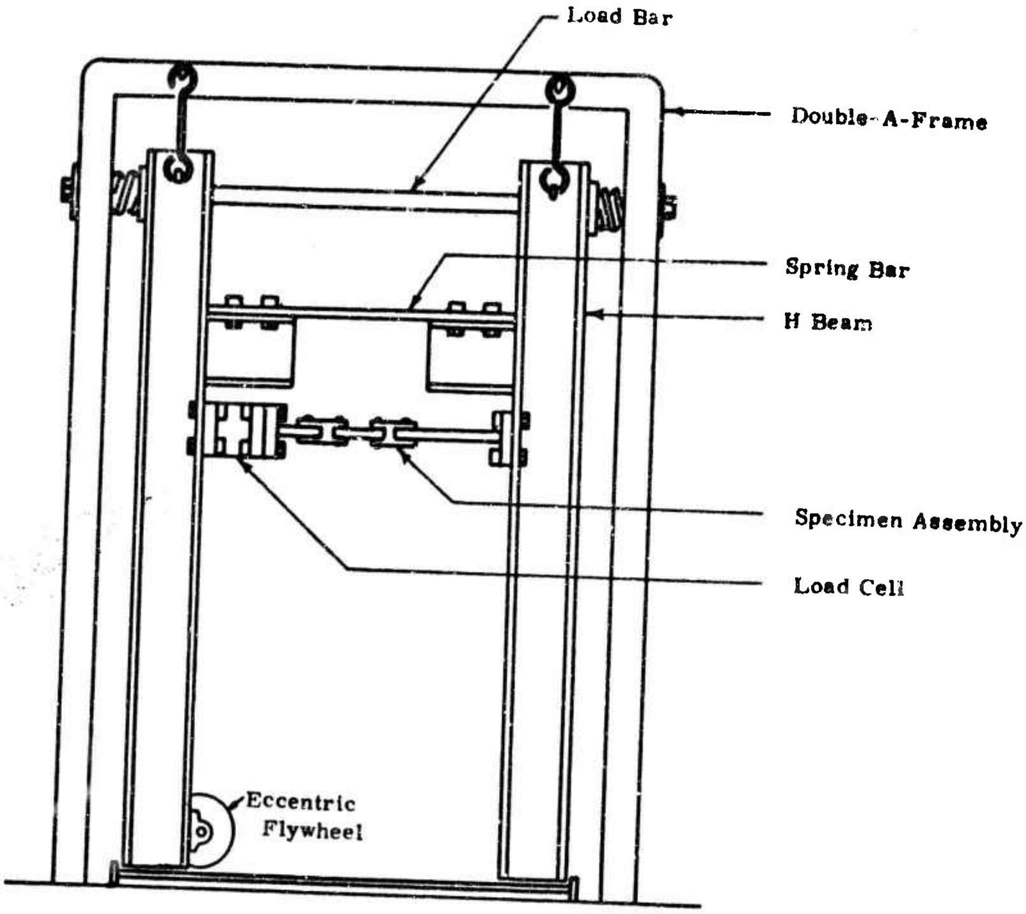


Figure 13. Schematic Drawing of Axial-Loading Fatigue Machine.

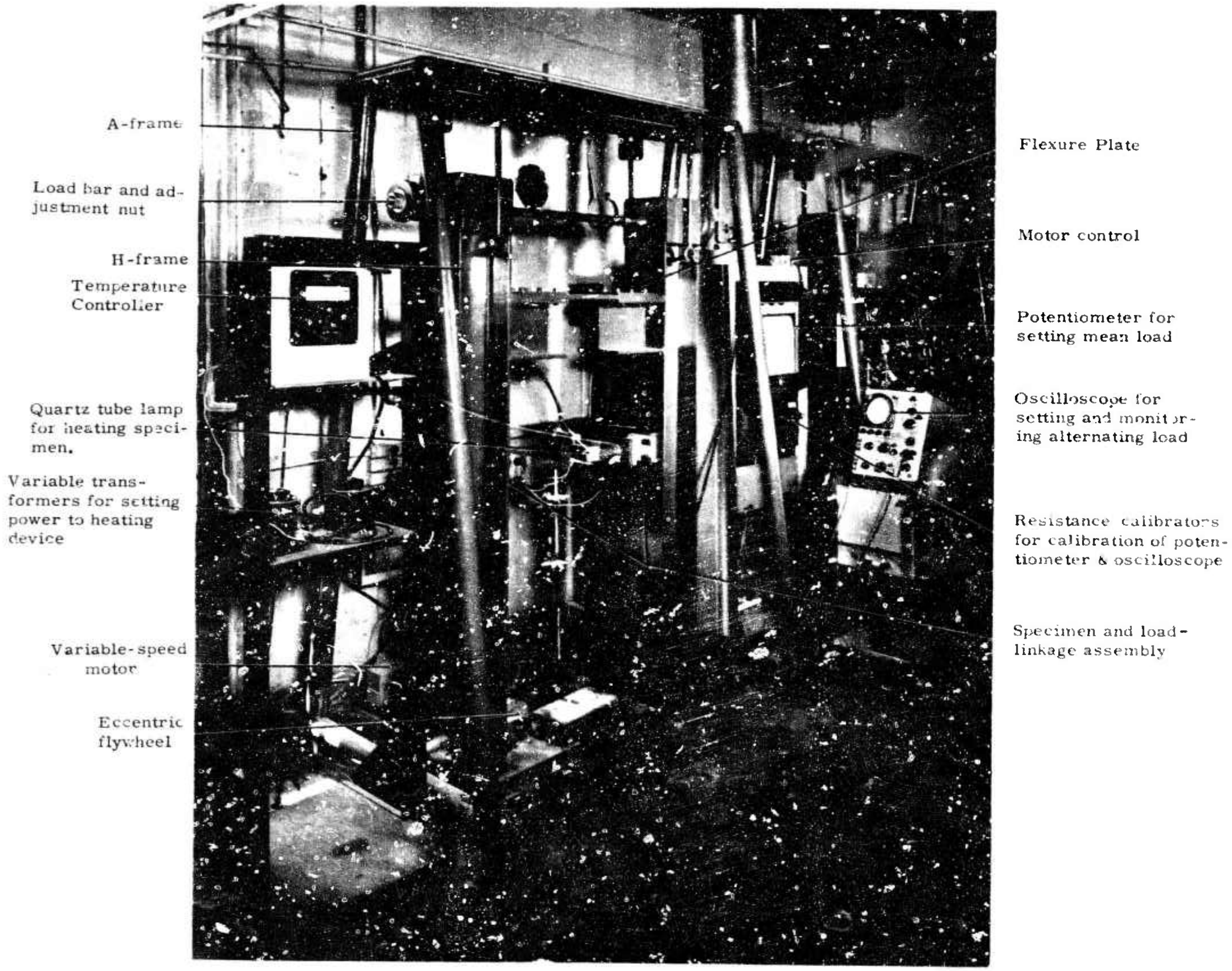


Figure 14. Axial-Fatigue Machines and Related Apparatus.

Figure 15 shows the design of the bar- and sheet-type specimens to which all specimens were machined early in the program. The notched ends of the bar specimens were machined to fit grips that had been used previously with the fatigue equipment for other materials. In early tests in this program numerous failures occurred in the reduced section of the shoulders which necessitated a change in the method of gripping the bar specimen. The method adapted was a simple friction grip which was clamped to the cylindrical shoulder surfaces of the specimens. For both the sheet and bar specimens, aluminum shims were used between the grip surfaces and the specimens to prevent fretting-corrosion and failure near the grip-specimen interface. After the shoulder-failure problem was encountered, the scope of the program was revised to use half of the available fatigue specimens to determine the fatigue properties of the alloys at a stress concentration, K_t, of 3. Notches, as shown in Figure 16, were machined in approximately half of the unnotched specimens for these evaluations.

The method of gripping and heating the bar and sheet specimens is illustrated in Figures 17 and 18. For the evaluations at 400 and 800° F, temperature was measured and controlled by thermocouples that were held in contact with the surface of the specimens by a spring clamp. Two variable transformers and a controller were used to achieve partial on-off control of the temperature. With this system the indicated temperature was controlled to within 5° F of the nominal test temperature. Stresses were selected to establish S-N curves from 10^4 to 10^7 cycles. Tests in which the specimen did not fracture within 10^7 cycles were discontinued.

Impact

A Sonntag impact machine with range capacities of 0-25, 0-60, 0-100, and 0-240 ft-lb was used for the impact tests. Figure 19 shows the dimensions of the standard Charpy V-notch specimen that was used. For evaluations at 400, 600, and 800° F specimens were heated in a small electric muffle furnace. They were heated to 10° F above the desired temperature at impact to compensate for the decrease in temperature during transfer from the furnace to the testing machine, which required less than 5 seconds.

Fracture Toughness

Fracture-toughness was determined for the sheet alloys from center-notched, fatigue-cracked specimens, shown in Figure 20, and for the bar alloys from edge-notched, fatigue-cracked specimens, shown in Figure 21. An axial-fatigue machine, described previously in this report, was used to fatigue crack the sheet specimens. The bar specimens were fatigue cracked by a motor-driven eccentric cam that flexed the free end of the specimen. The specimen

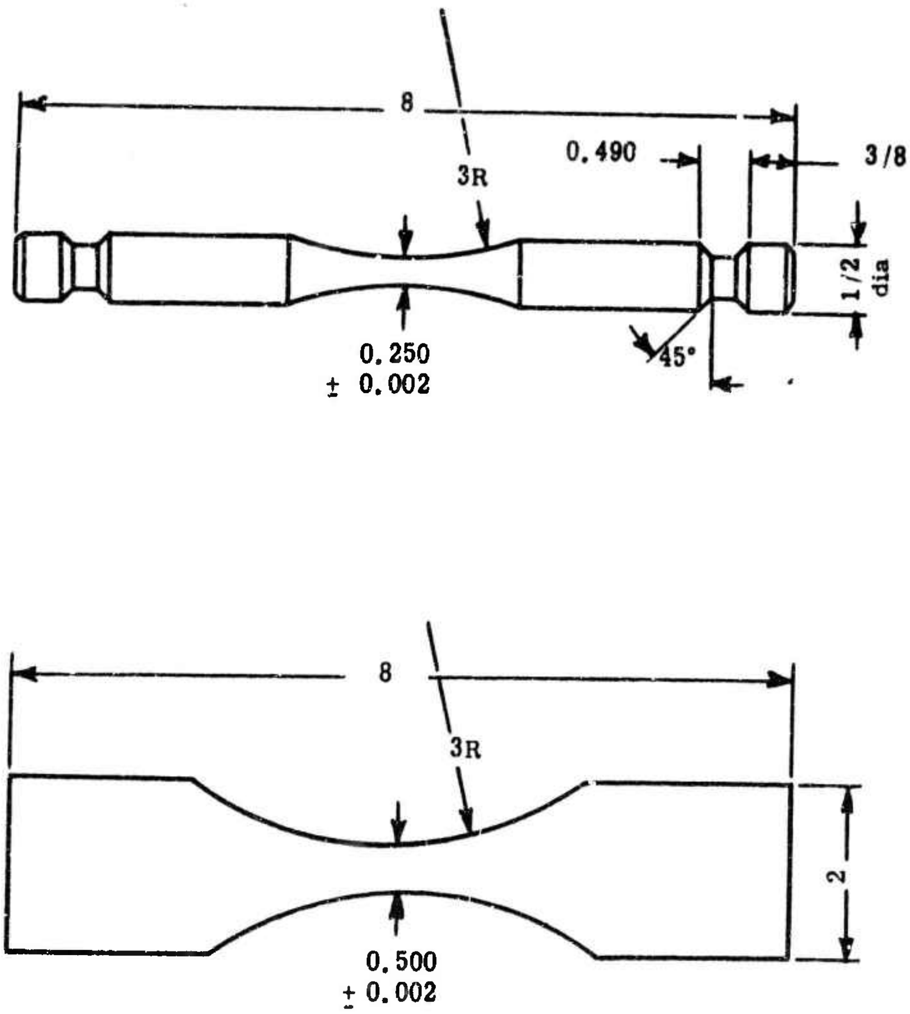


Figure 15. Unnotched Fatigue Specimens for Bar (above) and Sheet (below) Materials

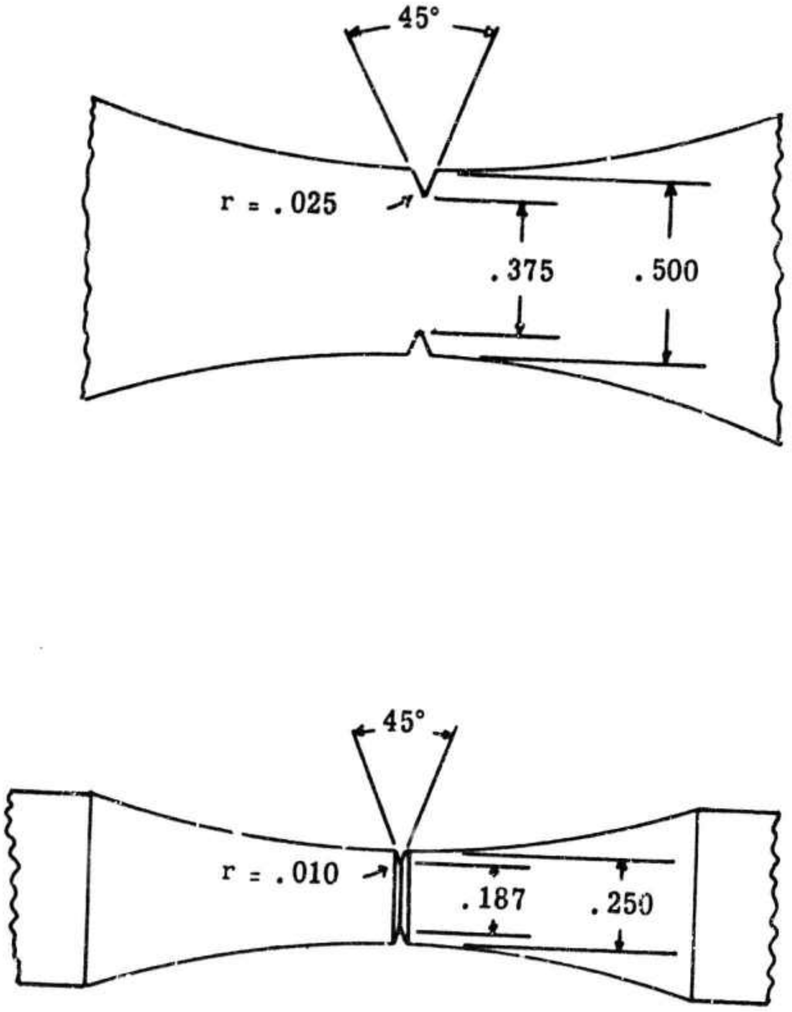


Figure 16. Notched Section of Fatigue Specimens for Sheet (above) and Bar (below) Materials.

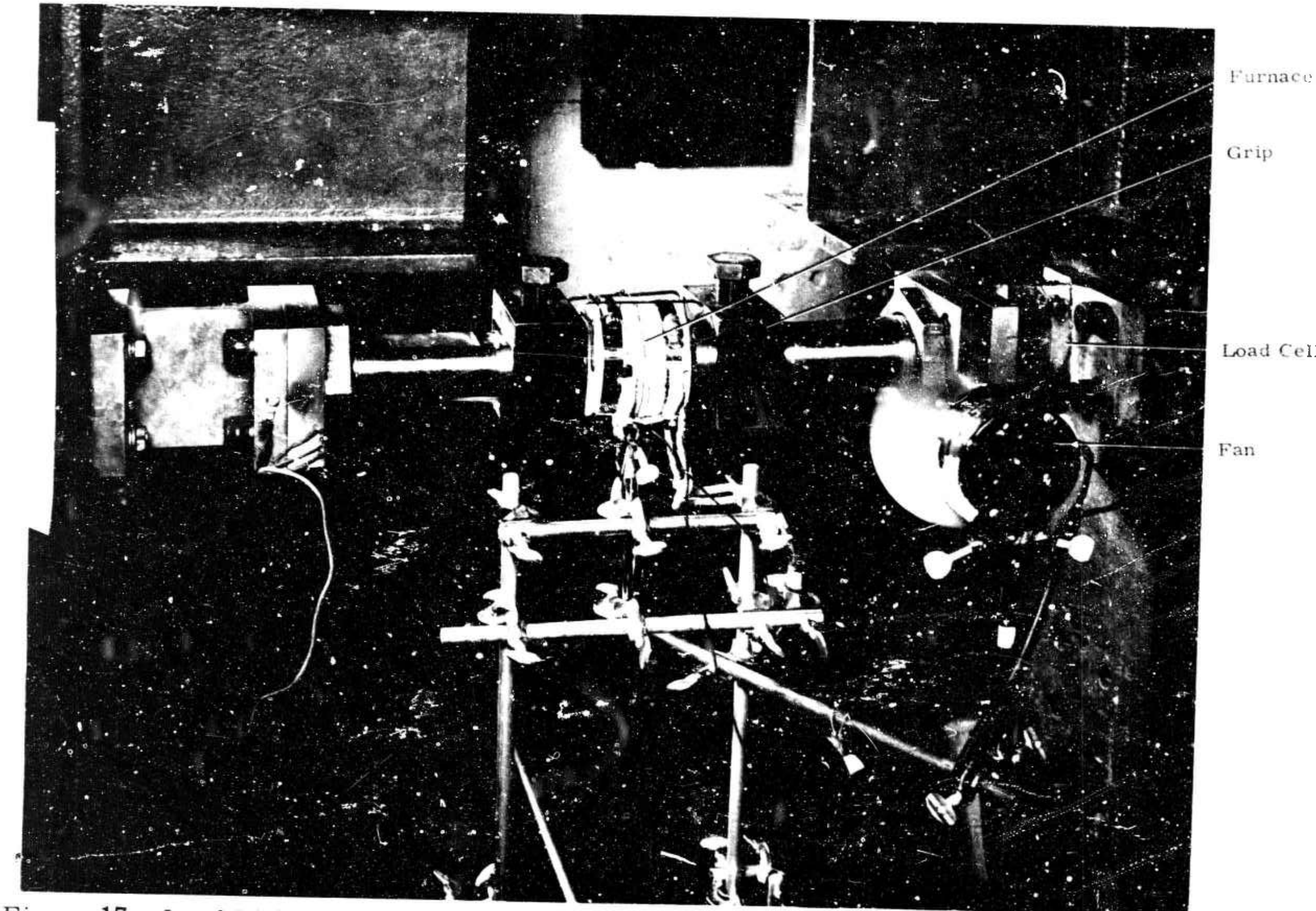


Figure 17. Load Linkage Assembly and Furnace for Axial-Fatigue Tests at Elevated Temperatures on Bar Specimens.

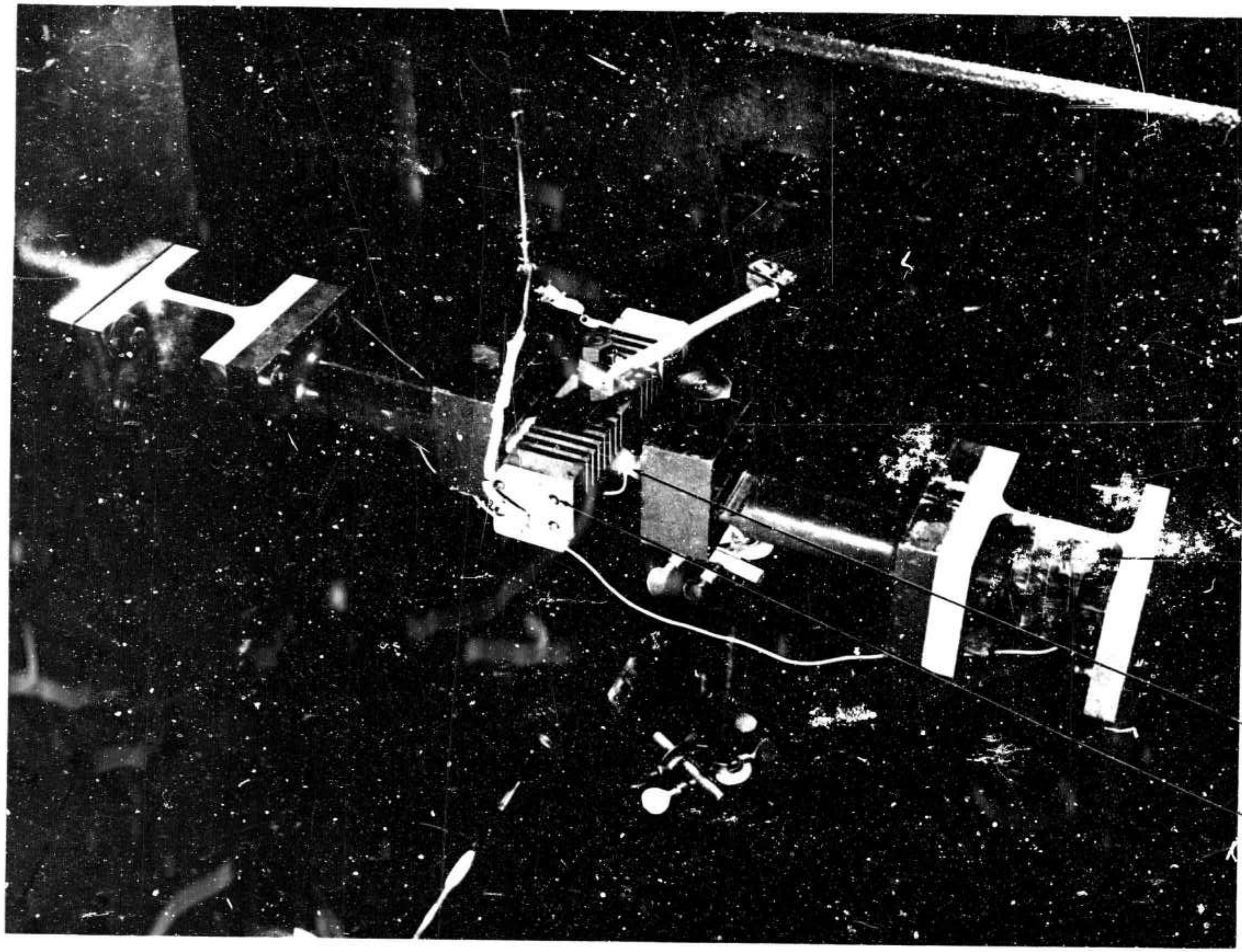
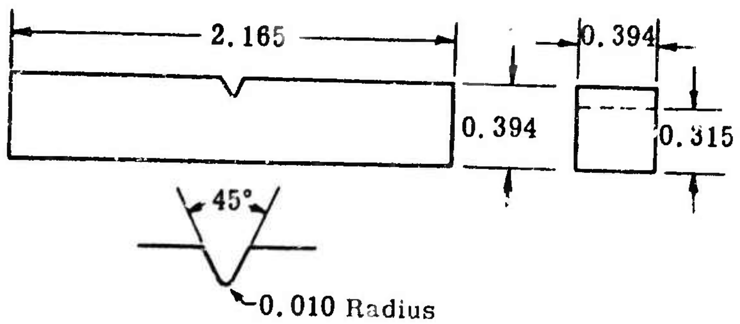


Figure 18. Load-Linkage Assembly for Fatigue Tests on Sheet Alloys



(b)

Figure 19. Charpy V-Notch Impact Specimen.

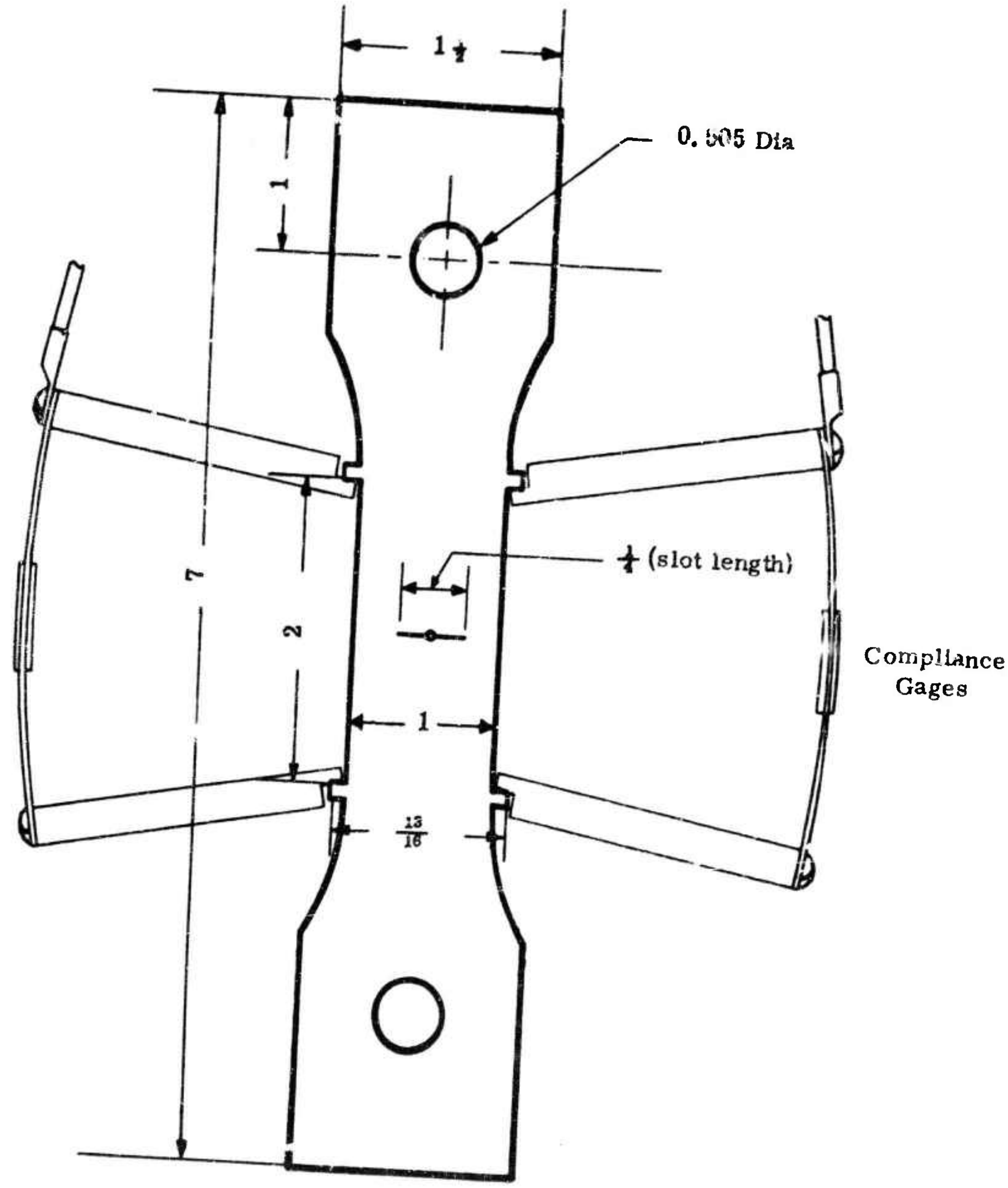


Figure 20. Fracture-Toughness Specimen and Compliance Gage for Sheet Alloys

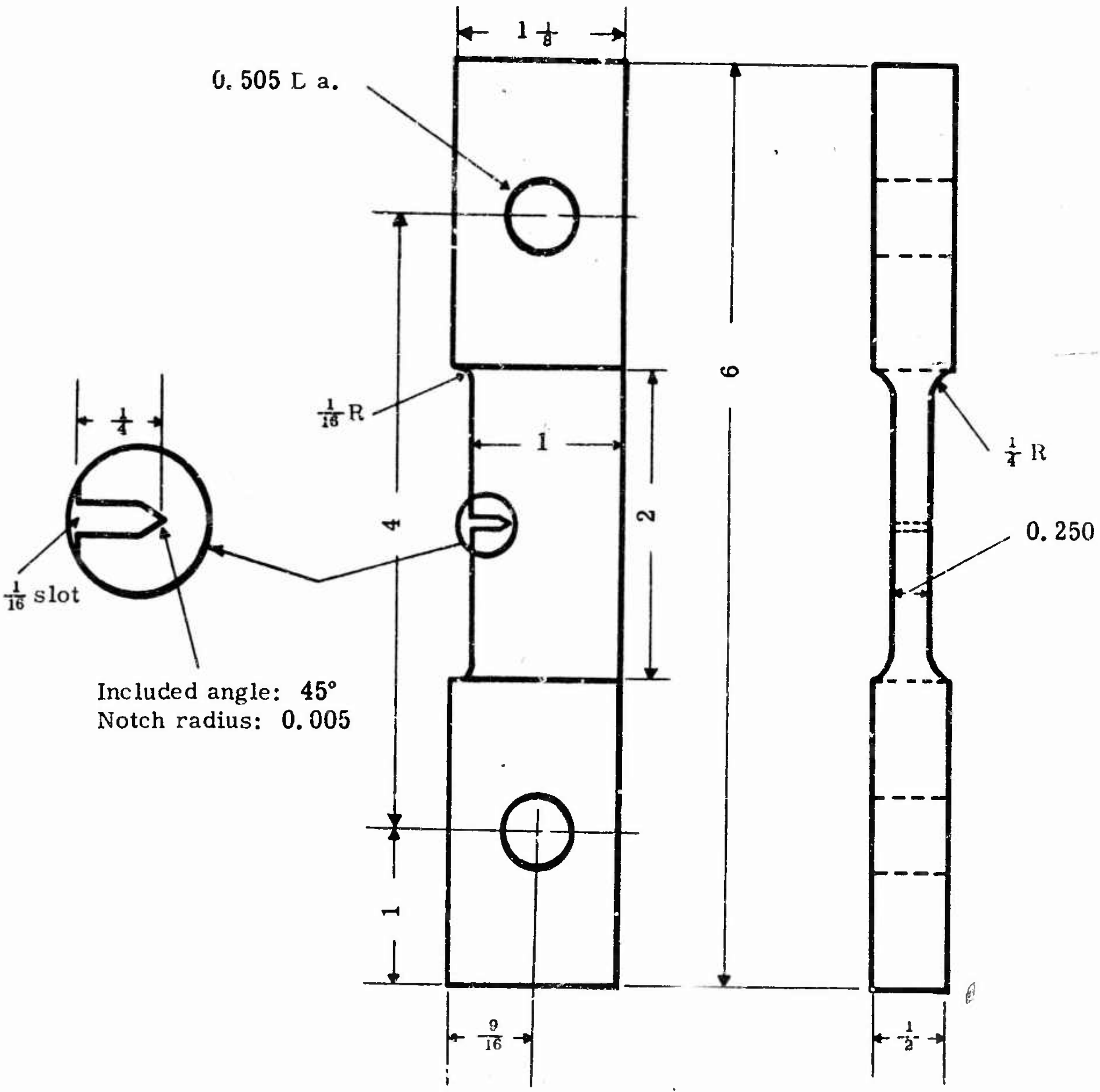


Figure 21. Fracture Toughness Specimen Used for Bar Alloys

was supported as a cantilever beam such that the notched edge of the specimen was loaded in tension as the free end was deflected. A universal testing machine, suitably instrumented, was used to perform the fracture-toughness tests. Quartz-tube, tungsten-element lamps were used to heat the specimens for tests at 400° F. For the tests at -110° F, the specimens were cooled in a gas cryostat by gaseous nitrogen that was refrigerated by passage through a copper coil immersed in a flask of liquid nitrogen. The gaseous nitrogen was metered into the cryostat through a solenoid valve that was actuated by the signal from a thermocouple in contact with the specimen at the notch.

A compliance gage, which has been described in detail in another report[3], was used with both sheet and bar specimens to determine the load at which crack extension occurred. Figure 20 shows the compliance gage attached to a sheet specimen. The sensitive elements of the compliance gage are resistance strain gages which were bonded to the flexure spring of the compliance gage. The signal from the compliance gage was recorded against load on an X-Y recorder. An acoustical pick-up was attached to the specimen near the crack in an attempt to detect "pop-in." The signal from this pick-up was recorded against deformation on another X-Y recorder. Figure 22 is a reproduction of a load-extension curve for a sheet specimen on which the quantities measured for calculation of the fracture toughness are noted.

The plane-strain fracture toughness of the bar and sheet alloys and the plane-stress fracture toughness for the sheet alloys were calculated from formulae which are discussed in the literature[4,7]. The symbols in these formulae are given on pages xxix and xxx of this report.

(Bar alloys) $$K_{Ic} \text{ (or } K_{nc}) = \sqrt{\frac{(P/B)^2\ 1/w\left[7.59\ a/w - 32\ (a/w)^2 + 117\ (a/w)^3\right]}{(1-\nu^2)}} + \frac{eP}{Bw^{3/2}}\sqrt{139\,(a/w) - 221\,(a/w)^2 + 783\ (a/w)^3} \qquad (1)$$

(Sheet Alloys) $$K_{Ic} \text{ (or } K_{nc}) = \sqrt{\frac{\sigma^2 w \tan \pi a_0/w}{1-\nu^2}} \qquad (2)$$

(Sheet Alloys) $$K_c = \sqrt{\sigma^2 w \tan \pi\ a/w} \qquad (3)$$

Stress-Corrosion

The stress-corrosion work on the sheet alloys was performed in two stages: A, to determine the minimum susceptibility for stress-corrosion of each sheet alloy and, B, to determine the degradation in tensile properties of the sheet alloys after exposure of dry-salt-coated specimens at different time-temperature-stress parameters. The self-stressed specimen developed by NASA[2] was selected for the preliminary tests. Figure 23 shows the details

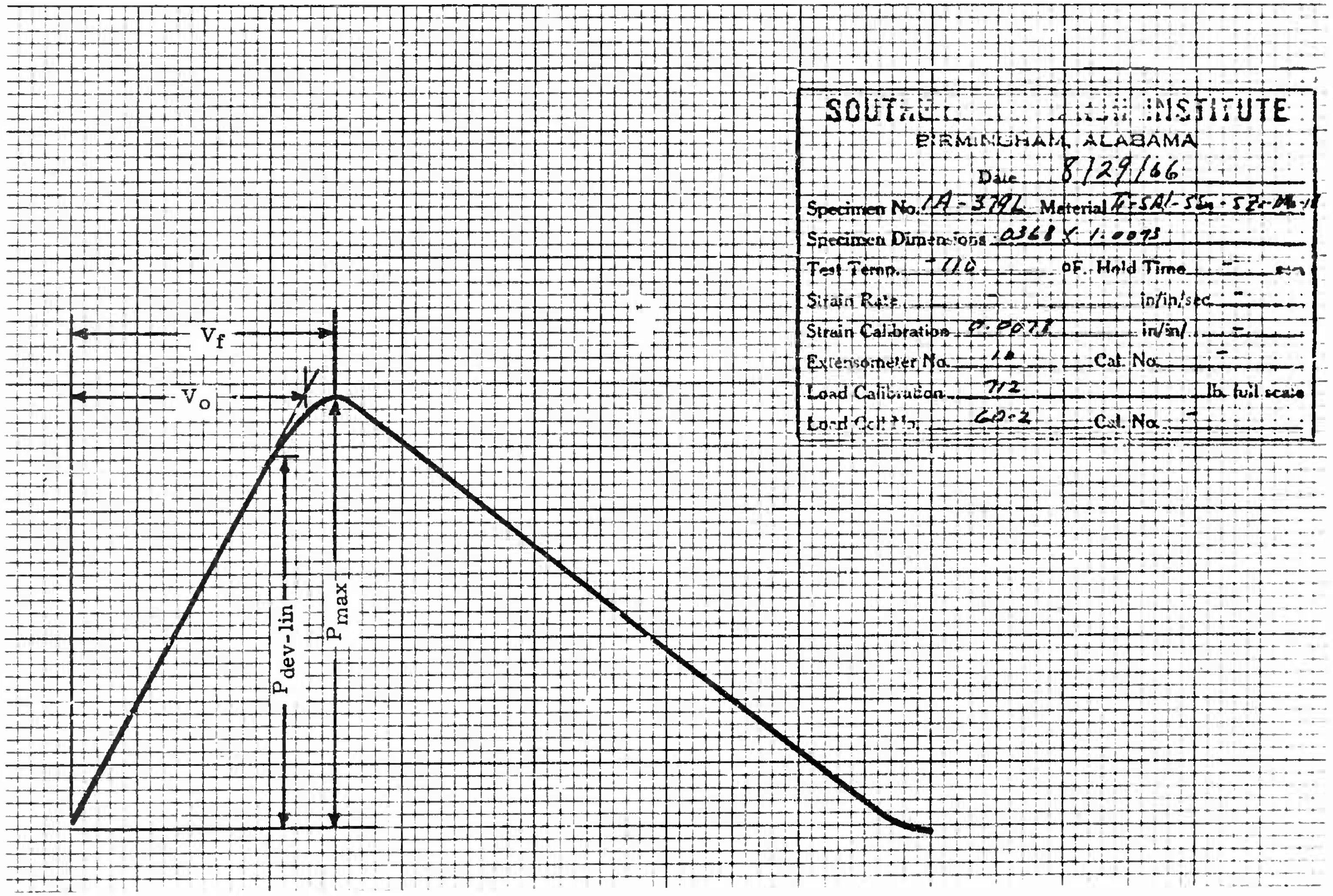
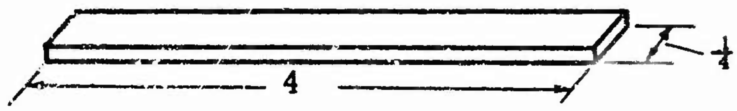
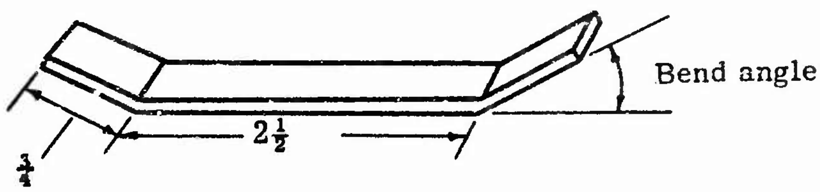


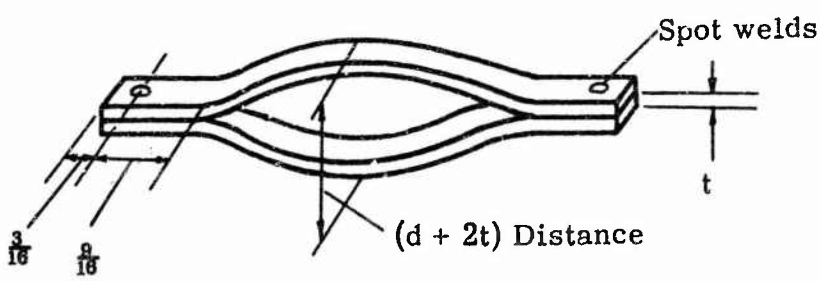
Figure 22. Reproduction of Load-Extension Curve for Center-Cracked Sheet Fracture-Toughness Specimens



(a) Machined strip.



(b) Strip with ends bent.



(c) Completed specimen.

Figure 23. Self-Stressed Corrosion Specimen

of the specimens. The bend angle of the ends of the strip was selected to produce a nominal maximum stress of 100,000 psi at room temperature. After coating the center one inch of each strip specimen with a super-saturated solution of NaCl in water, the specimens were dried and exposed at selected temperatures for different times. The criterion for embrittlement was the loss of bend ductility, which was determined by compressing the specimen along its longitudinal axis and measuring the relative displacement of the ends at fracture. If the specimen fractured before the ends were compressed into contact, the specimen was judged to have been embrittled by stress-corrosion.

In the second phase of the stress-corrosion work, the gage section of tensile specimens (Figure 5) was coated with NaCl, by the procedure given earlier, and stressed at 40, 60, and 80% of the tensile 0.2%-offset yield strength for 10 to 1000 hours at four different temperatures for each alloy. The exposure temperatures were from 500 to 900° F. Tensile tests were performed on the exposed specimens to determine the effect of exposure under different stress-time-temperature parameters on the residual properties. The specimens were exposed under stress in creep machines. The microstructures of selected specimens were examined after testing to determine the severity of corrosion.

Elastic-Moduli

The dynamic moduli of elasticity of the sheet and bar alloys were determined at 70, 400, 600, 800 and 1000° F, and the static moduli were determined at room temperature.

Resistance strain gages were employed to measure strain in tests to determine the moduli under static conditions. The specimens were loaded to different stress levels by calibrated weights acting through a 20:1 lever system of a creep frame. Strain at stresses through approximately 6000 psi were read from which the modulus of elasticity was calculated by Hooke's law:

$$E = \frac{S}{\epsilon} \tag{4}$$

The determination of the elastic modulus under dynamic conditions was accomplished by the vibrating-reed technique in which the natural frequency is used to calculate the dynamic modulus from -

$$E = \frac{4\,\rho\,l^4 f^2}{\pi^2 k^2 g \beta^4} \tag{5}$$

The symbols in this expression are identified on pages xxix and xxx. The end

correction factor, β, was 0.597. The fixed end of the 0.250-in.-wide x 6-in.-long reed was clamped in a massive iron block and the reed was plucked to excite it at its natural frequency. A stroboscope was used to determine the frequency. For the evaluations at elevated temperatures the block-and-reed assembly was heated in a split-tube furnace. The end of the reed was illuminated by the stroboscope through a pyrex window in one end of the furnace. Three thermocouples that were flash welded to the surface of an extra specimen, clamped in the block parallel to the test specimen, provided reference for control of the temperature level and uniformity by manual adjustment of variable transformers.

The apparatus used to determine the dynamic modulus of elasticity of the bar alloys was of the electrostatic type in which the specimen is driven into longitudinal resonance by a variable voltage acting across an air gap between one end of the specimen and a flat electrode of the apparatus. Figures 24 and 25 show two views of the apparatus. The variable voltage is applied by a signal generator and a power amplifier. The other end of the specimen and a plate serve to indicate resonance in the specimen by maxima in the alternating voltage between these elements at the resonating frequency. An oscilloscope is used to detect resonance and to observe the wave form. The resonant frequency is read from a frequency counter. The modulus of elasticity was calculated from -

$$E = \frac{4 l^2 \rho f^2}{g n^2} \qquad (6)$$

where "n" is the number of half wave lengths in the bar and the other notation is the same as in Equation 5. Three 20-gage iron-vs-constantan thermocouples, positioned near each end and the middle of the specimen, were used as temperature references for manual adjustment of the power to the three zones of the furnace for control of the level and uniformity of the temperature of the specimen.

Thermal Conductivity

The thermal conductivities of the alloys were measured using a comparative rod apparatus with AISI 316 steel conductivity references. The determination of thermal conductivity was accomplished by measuring both the heat flux density flowing axially through the cylindrical specimen and the temperature gradient along a known axial gage length. The heat flux density was determined with two heat meters or references of known conductivity placed coaxially at the top and bottom of the specimen, and the temperature gradient was measured by thermocouples installed in the specimens. Radial losses were carefully controlled with guard heaters. The uncertainty for this equipment is about $\pm 5\%$. This apparatus is described and discussed fully in Technical Report No. AFML-TR-65-133[5].

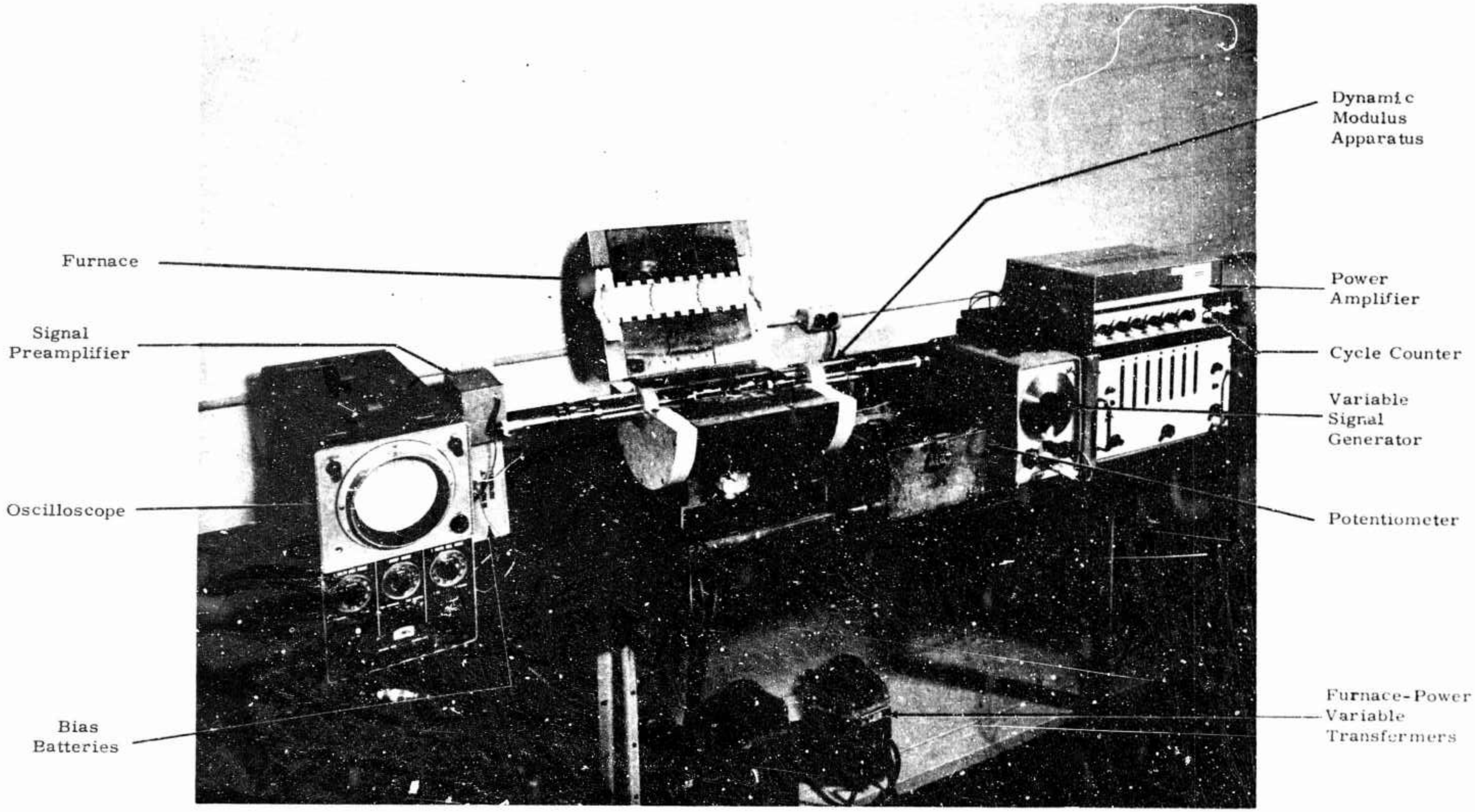


Figure 24. General View of Apparatus for Determination of Dynamic Modulus of Elasticity of Bar Specimens

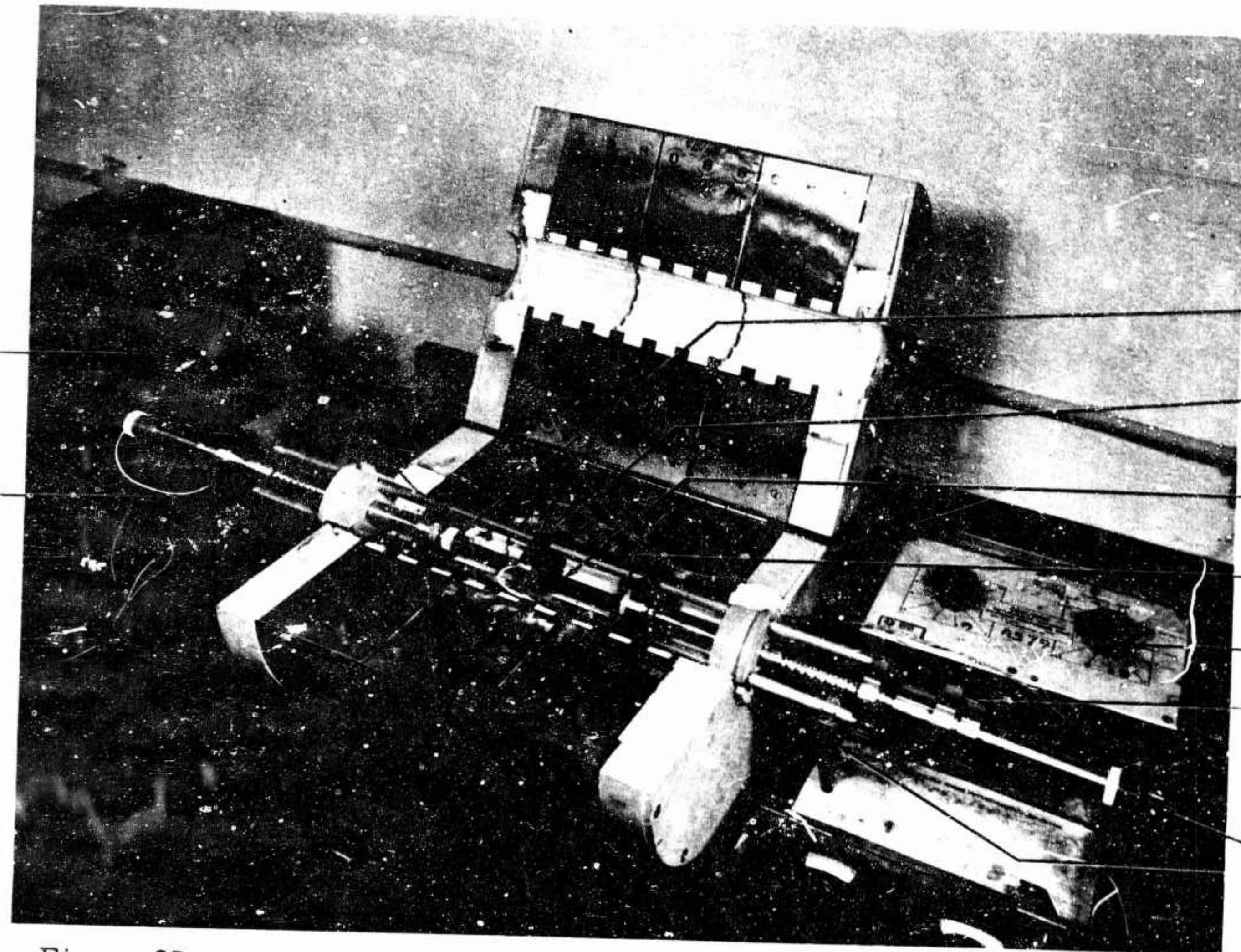


Figure 25. Furnace and Excitation Frame of Dynamic-Modulus Apparatus

The conductivities were measured transverse to the rolling direction of the bar materials and parallel to the rolling direction of the sheet. The specimen configurations are shown in Figure 26. To make the sheet specimens, squares of 0.040-inch-thick sheets were tightly clamped together to form small cubes. Single welds perpendicular to the sheets were made at opposite ends of the cubes using an inert-gas arc welder. The specimens were then machined as shown in Figure 26. Most of the weld area was removed in machining, and the thermocouple holes were placed outside the heat-affected zone of the weld. Three thermocouples were placed in small holes on the periphery of the specimen to detect any nonuniform temperature distribution.

Thermal Expansion

The thermal expansions of the alloys were determined using a quartz-tube dilatometer with mechanical dial gages graduated in 0.0001 in. divisions. Specimens machined from bar stock were 1/2 in. x 5/8 in. x 3 inches long. Specimens from the sheet stock were made by rolling the sheet into cylinders of about 3/4 in. diameter x 3 inches long and tack welding the joint in two places. The specimens were fitted with end caps made from Ti-5Al-5Sn-5Zr bar stock. These end caps added only about 1/8 inch to the total length of the specimen. The thermal expansions measured for the sheet alloys included those of both the specimen and end caps. The data were corrected for the expansion of the end caps, but this correction was not significant since the expansions of the specimen and end caps were almost identical, and the total length of the end caps was only $\frac{1}{24}$ the length of the specimen. The data were also corrected for the expansion of the quartz dilatometer. Thermocouples were flash welded to the specimen surfaces to monitor temperature. At least two thermocouples, and usually three, were located at different points along the axis of the specimen to detect any gradients.

The dilatometers and the experimental procedures are fully described in Technical Report No. AFML-TR-65-133[5].

Heat Capacity

The heat capacities of the alloys were determined using an adiabatic calorimeter. With this apparatus the heated specimen was dropped into a thermally guarded, calibrated cup, and specimen enthalpy was measured as a function of the increase in temperature of the cup. Specimens from the bar stock were one-half-inch cubes, and the sheet specimens consisted of about three or four small pieces. The heat capacities were determined from the slopes of the enthalpy versus temperature curves. Heat capacity was determined

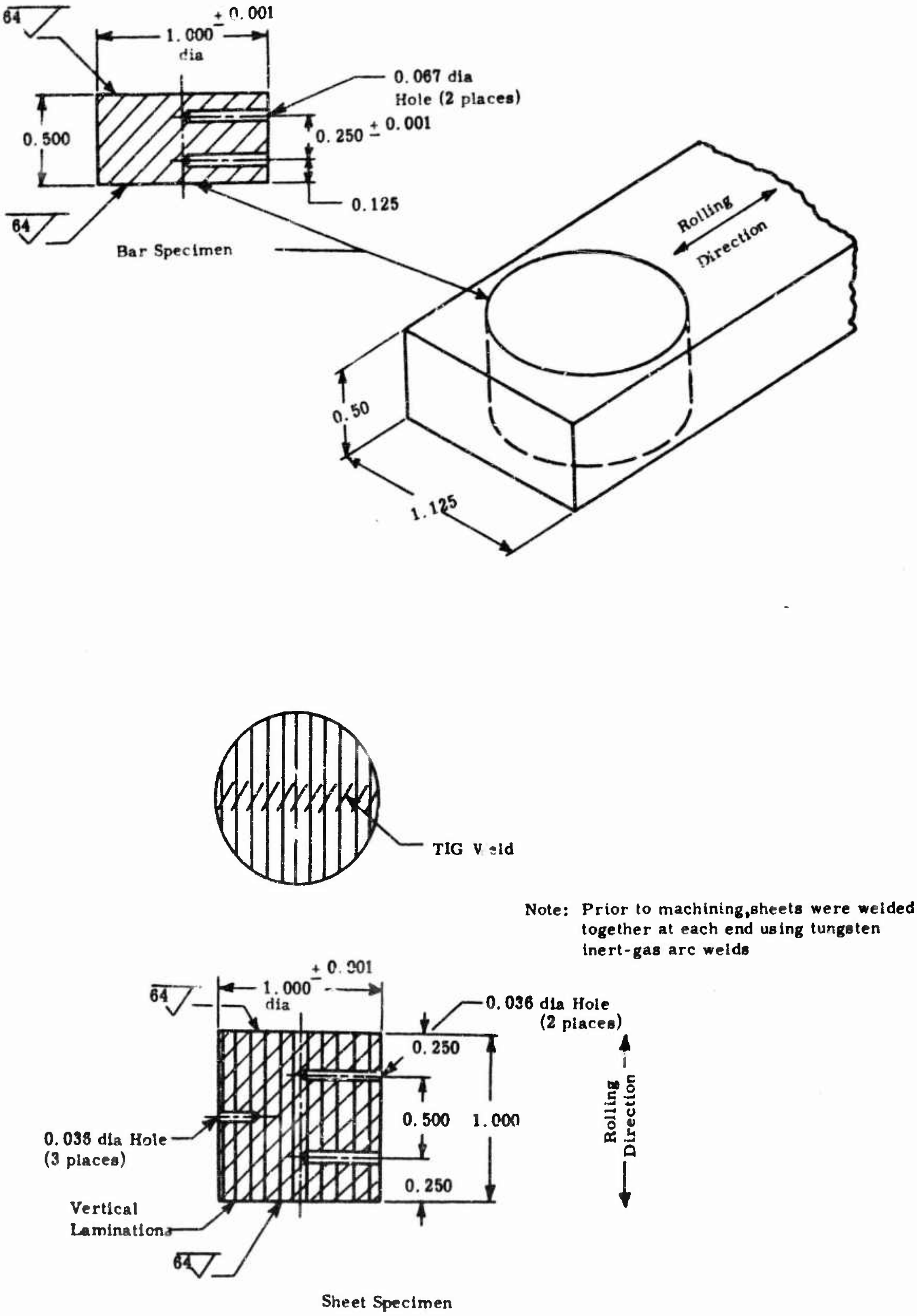


Figure 26. Configuration and Orientation of Thermal Conductivity Specimens

graphically and also by using the least squares method to fit the enthalpy data to an equation of the form

$$h_{85} = aT + bT^2 + cT^{-1} + d \qquad (7)$$

The derivative of this equation was adjusted to agree with the graphically determined heat capacity at 150° F to obtain an equation for heat capacity

$$HC = a + 2bT - c* T^{-2} \qquad (8)$$

This apparatus and the procedures used are also fully discussed in Technical Report No. AFML-TR-65-133[5]. The overall uncertainty of this apparatus was established at ± 5%.

RESULTS OF MECHANICAL-PROPERTY TESTS

Sheet Alloys

Tensile

Results of tensile tests on the sheet alloys may be found in the following figures and tables:

Alloy	Figures	Tables[a]
Ti-5Al-5Sn-5Zr	27, 28, 29, 36, 37, 38	9, 12, 13, 36, 37, 42
Ti-5Al-5Sn-5Zr-1Mo-1V	30, 31, 32, 36, 37, 38	10, 12, 13, 38, 39, 42
Ti-6Al-2Sn-4Zr-2Mo	33, 34, 35, 36, 37, 38	11, 12, 13, 40, 41, 42

[a] Tables with numbers underlined are in Appendix I.

Tabulated tensile-property data in Tables 9, 10, and 11 and plotted data in Figures 27 - 35 represent averages of ten determinations at each temperature and orientation. No significant differences were detected in the tensile properties between the two heats of each sheet alloy. Likewise, there was not a significant difference in the tensile properties between the longitudinal and transverse orientations for the sheet alloys, with the exception of the possible lower strength of Heat No. V-3076 with respect to Heat V-3016 of the Ti-6Al-2Sn-4Zr-2Mo alloy as shown in Table 11.

Results of the precision-modulus of elasticity determinations on the sheet alloys are given in Table 12. The modulus-of-elasticity data obtained in the conventional tensile tests are in good agreement with these data, except the value for the modulus of elasticity in the longitudinal direction of the Ti-5Al-5Sn-5Zr-1Mo-1V alloy from Heat V-2957 in the tensile tests was low relative to the value obtained from the measurements with the resistance strain gages.

Figures 36 - 38 show the tensile properties of the three sheet alloys evaluated in this investigation relative to each other and relative to the properties of one all-alpha alloy (Ti-5Al-2.5Sn) and one alpha-beta alloy (Ti-6Al-4V), for which data were available as referenced in the figures. Averaged properties for the two heats and two orientations for the three alloys evaluated in this program are shown in these figures. As these figures show, the tensile strength properties of the two alpha-beta alloys, Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo, were higher at all test temperatures than the properties of the Ti-6Al-4V alpha-beta alloy. The rate of decrease of tensile strength with respect to temperature

Table 9

Summary of Averages and Standard Deviations for the Tensile Properties of the Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures[a, b, c]

Heat No. D-6060

Temp °F	Orientation	F_{ty}, ksi Avg.	F_{ty}, ksi s	F_{tu}, ksi Avg.	F_{tu}, ksi s	e, % Avg.	e, % s	E_t, 10^6 psi Avg.	E_t, 10^6 psi s
70	L	118.6	1.0	128.5	0.8	14.1	1.0	16.1	0.5
400	L	79.2	0.6	97.5	0.5	18.4	0.9	13.9	0.7
600	L	66.3	0.7	89.6	0.7	18.4	1.3	12.2	1.1
800	L	61.1	2.2	83.5	1.1	23.1	1.6	12.1	1.4
1000	L	59.0	1.1	79.4	0.8	21.2	1.1	11.1	1.6
70	T	118.5	0.7	127.0	0.7	14.9	0.6	16.6	0.7
400	T	78.6	0.6	93.3	0.4	20.2	0.6	14.4	1.3
600	T	65.5	0.4	85.0	0.6	20.2	1.1	13.5	1.1
800	T	60.1	0.8	79.6	0.9	26.6	2.4	12.8	1.2
1000	T	57.9	0.4	75.1	0.6	24.3	1.1	11.9	0.8

Heat No. D-1793

Temp °F	Orientation	F_{ty}, ksi Avg.	F_{ty}, ksi s	F_{tu}, ksi Avg.	F_{tu}, ksi s	e, % Avg.	e, % s	E_t, 10^6 psi Avg.	E_t, 10^6 psi s
70	L	116.2	0.8	124.5	0.6	17.2	1.3	15.4	0.6
400	L	80.8	2.2	96.9	1.2	18.6	0.8	13.8	1.5
600	L	68.3	3.3	91.0	0.6	23.7	1.4	12.9	1.0
800	L	62.6	1.0	84.7	0.7	23.4	0.8	12.1	0.6
1000	L	62.4	0.4	82.1	0.7	23.8	1.1	10.5	0.5
70	T	115.4	0.6	122.1	0.7	17.9	0.6	15.5	0.5
400	T	79.9	0.9	92.8	0.9	20.2	0.2	13.4	0.8
600	T	67.9	0.8	86.4	0.8	24.5	1.6	13.6	0.4
800	T	62.5	0.9	81.3	0.6	26.4	1.0	13.4	0.9
1000	T	61.5	0.7	78.1	0.6	25.3	1.5	11.3	0.8

a Averages and standard deviations are based on 10 evaluations at each temperature for each orientation.

b Heat treatment: 1650° F, 1/2 hr, A.C.

c Sheet thickness: 40 mils.

Table 10

Summary of Averages and Standard Deviations for the Tensile Properties of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures[a, b, c]

Heat No. V-2957

Temp		F_{ty}, ksi		F_{tu}, ksi		e, %		E_t, 10^6 psi	
° F	Orientation	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	L	136.8	1.1	146.8	1.2	10.6	0.7	14.6	0.2
400	L	105.9	1.3	123.1	1.5	9.5	0.4	13.2	0.5
600	L	97.6	0.6	120.2	1.0	9.8	0.6	12.3	0.5
800	L	92.8	0.9	120.2	1.4	12.3	0.7	12.2	0.5
1000	L	83.3	0.5	108.2	1.1	12.5	1.0	12.0	0.6
70	T	137.9	1.7	147.0	0.7	10.2	1.1	15.8	0.5
400	T	109.6	1.6	122.6	1.7	8.3	0.4	13.9	0.5
600	T	101.5	1.1	117.9	0.7	8.0	0.4	13.4	0.5
800	T	95.8	0.7	117.3	1.1	11.7	0.8	13.3	0.6
1000	T	87.3	1.3	107.5	0.8	10.8	0.9	12.2	0.7

Heat No. V-1991

Temp				F_{tu}, ksi		e, %		E_t, 10^6 psi	
° F	Orientation	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	L	138.1	1.9	149.5	1.8	12.3	0.7	15.3	0.6
400	L	106.6	1.3	124.2	0.7	11.0	1.6	13.4	0.7
600	L	96.6	0.8	119.8	1.2	11.0	0.8	12.7	1.0
800	L	92.8	0.5	117.6	0.9	12.0	0.7	12.0	0.5
1000	L	81.6	2.7	104.9	1.6	12.5	1.0	11.3	0.7
70	T	138.1	1.9	146.8	2.1	11.7	0.8	16.1	0.5
400	T	109.1	1.2	122.0	1.5	8.6	0.5	14.4	0.5
600	T	99.9	1.6	115.4	1.6	9.4	0.7	12.3	0.6
800	T	94.8	1.3	114.0	1.4	12.7	1.2	12.7	0.8
1000	T	84.6	1.7	102.3	1.8	11.5	0.8	11.4	0.4

a Averages and standard deviations are based on 10 evaluations at each temperature for each orientation.

b Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

c Sheet thickness: 40 mils

Table 11

Summary of Averages and Standard Deviations for the Tensile Properties of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures[a, b, c]

Heat No. V-3016

Temp °F	Orientation	F_{ty}, ksi Avg.	s	F_{tu}, ksi Avg.	s	e, % Avg.	s	E_t, 10^6 psi Avg.	s
70	L	142.2	2.7	147.7	3.3	12.2	1.3	16.2	0.4
400	L	106.9	2.5	121.2	3.3	11.1	0.9	14.4	0.9
600	L	95.9	1.8	115.0	2.2	9.1	1.5	13.3	1.1
800	L	91.7	3.1	113.8	3.6	11.2	1.8	13.7	1.1
1000	L	85.0	2.9	105.8	3.8	13.1	2.0	11.5	0.9
70	T	139.1	1.2	144.4	1.6	11.6	2.1	15.9	0.3
400	T	104.6	1.6	118.2	2.6	11.4	1.3	14.8	1.2
600	T	93.2	1.8	112.0	2.3	10.2	0.8	13.7	0.9
800	T	88.7	1.6	111.3	1.6	11.8	1.4	12.3	0.7
1000	T	83.7	2.1	105.1	2.3	13.9	0.9	11.5	0.8

Heat No. V-3076

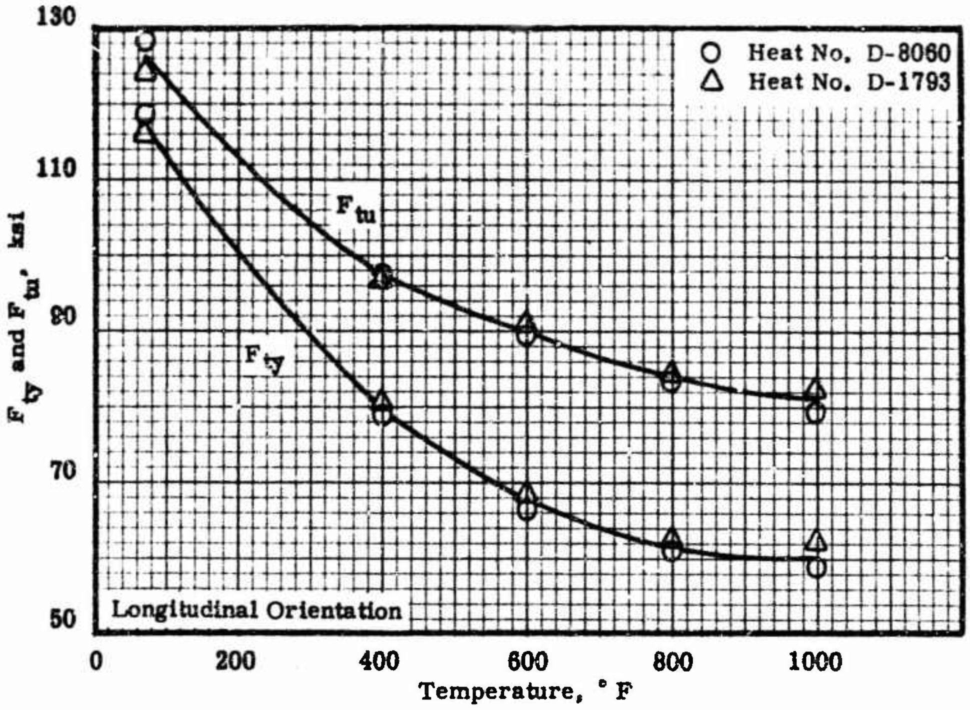
Temp °F	Orientation	F_{ty}, ksi Avg.	s	F_{tu}, ksi Avg.	s	e, % Avg.	s	E_t, 10^6 psi Avg.	s
70	L	141.9	1.9	151.1	3.0	10.8	0.6	16.6	0.4
400	L	109.7	1.7	126.2	1.8	9.8	0.8	14.5	0.6
600	L	98.9	2.1	119.3	2.3	7.6	0.7	14.7	0.8
800	L	93.7	1.9	116.6	2.5	8.8	0.9	13.7	1.3
1000	L	83.5	3.1	108.0	3.2	13.3	2.2	13.2	0.9
70	T	134.7	1.0	145.5	1.4	11.4	0.7	15.6	0.4
400	T	102.8	0.6	120.9	0.8	10.9	0.8	14.4	1.7
600	T	92.4	0.6	115.5	0.6	9.1	0.1	13.2	0.8
800	T	87.8	0.8	113.8	0.9	10.8	1.0	12.5	0.8
1000	T	79.8	1.3	103.2	0.9	13.8	1.8	11.1	0.3

---

a Averages and standard deviations are based on 10 evaluations at each temperature for each orientation.

b Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

c Sheet thickness: 40 mils.



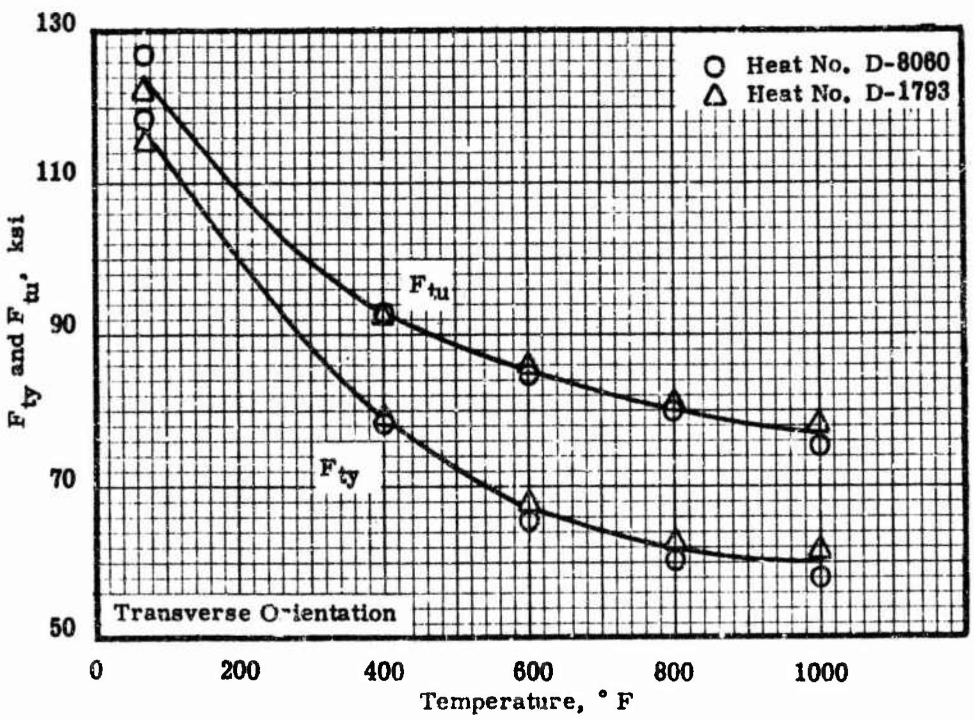
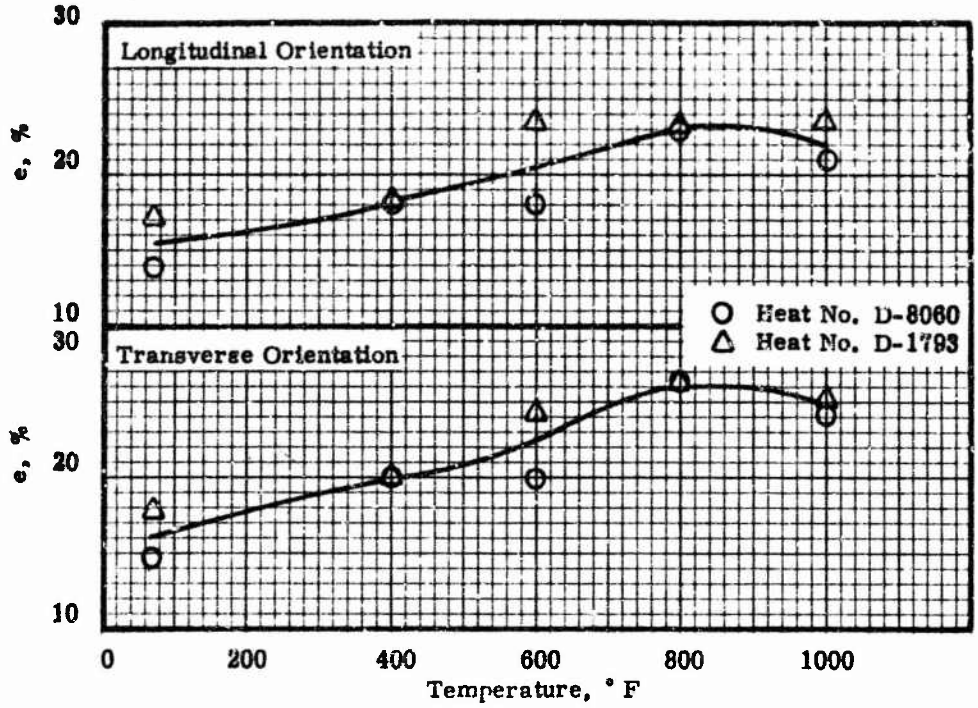


Figure 27. The 0.2%-Offset Yield Strength and Tensile Strength of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures.

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.



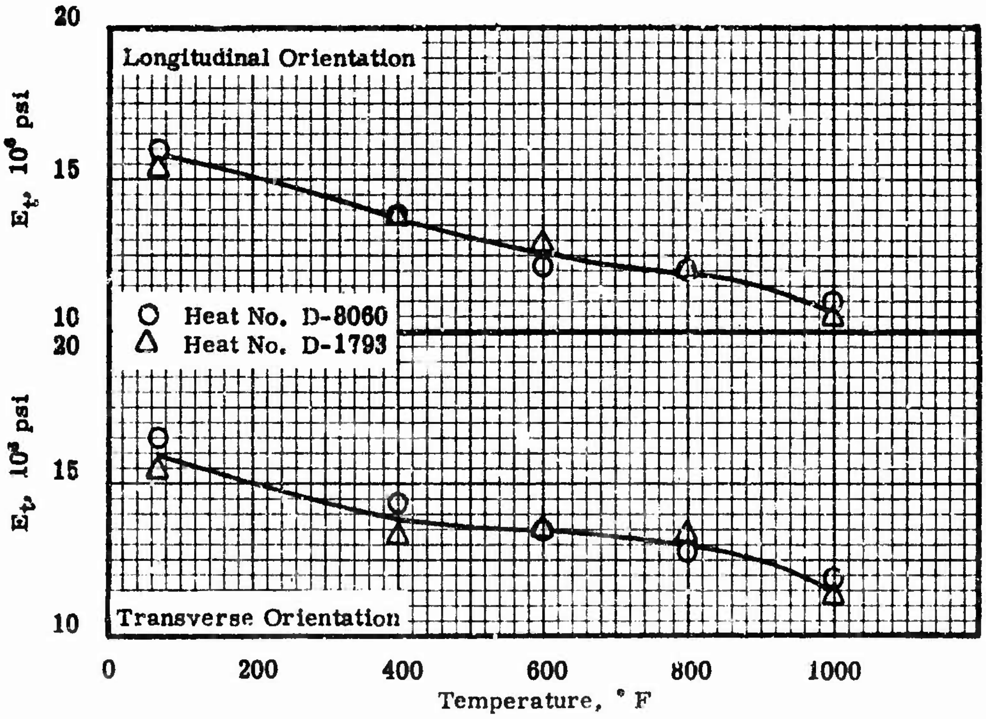


Figure 28. The Percent Elongation and Modulus of Elasticity in Tension of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures.

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

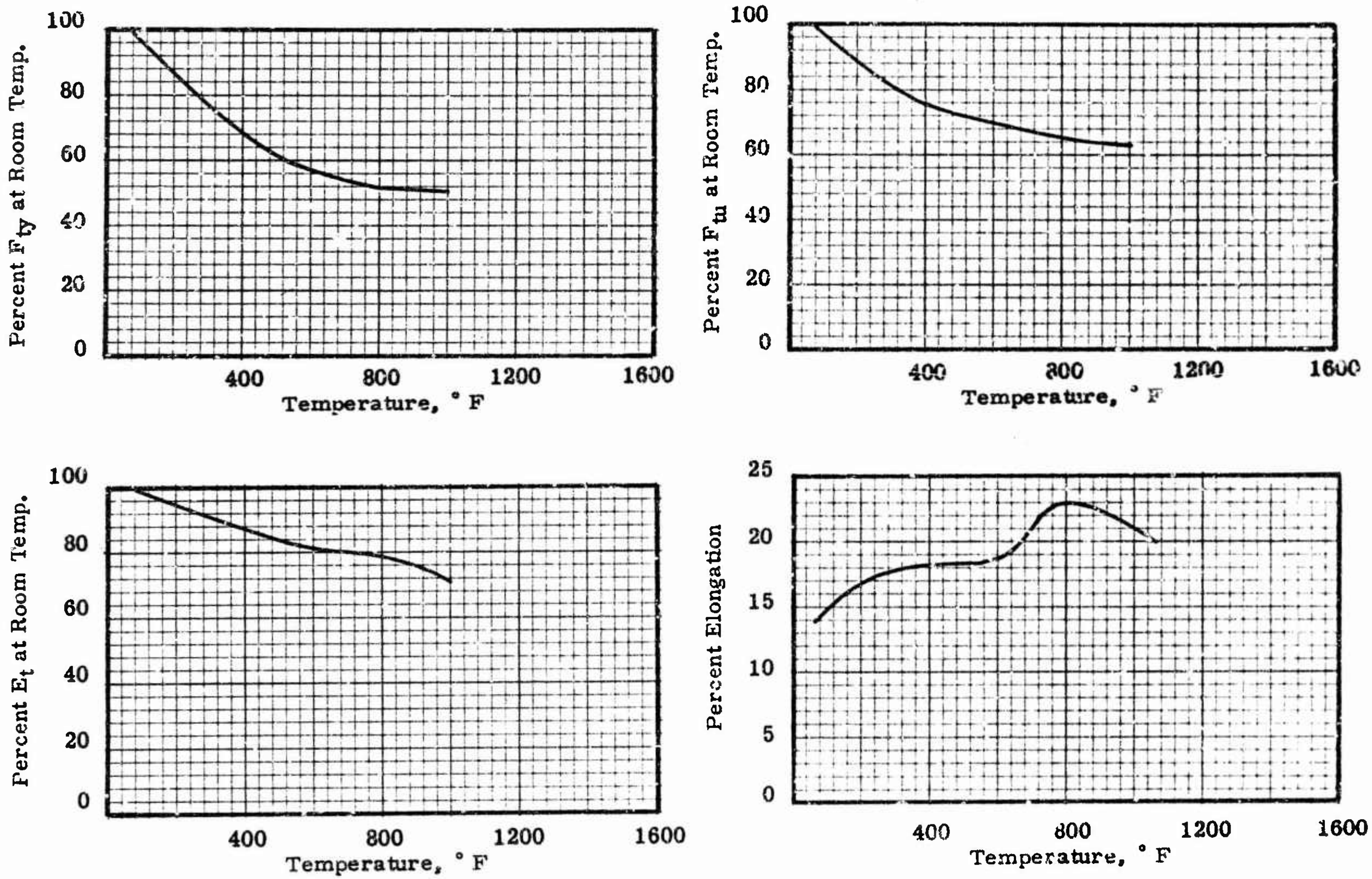


Figure 29. The Effect of Temperature on the Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Sheet

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

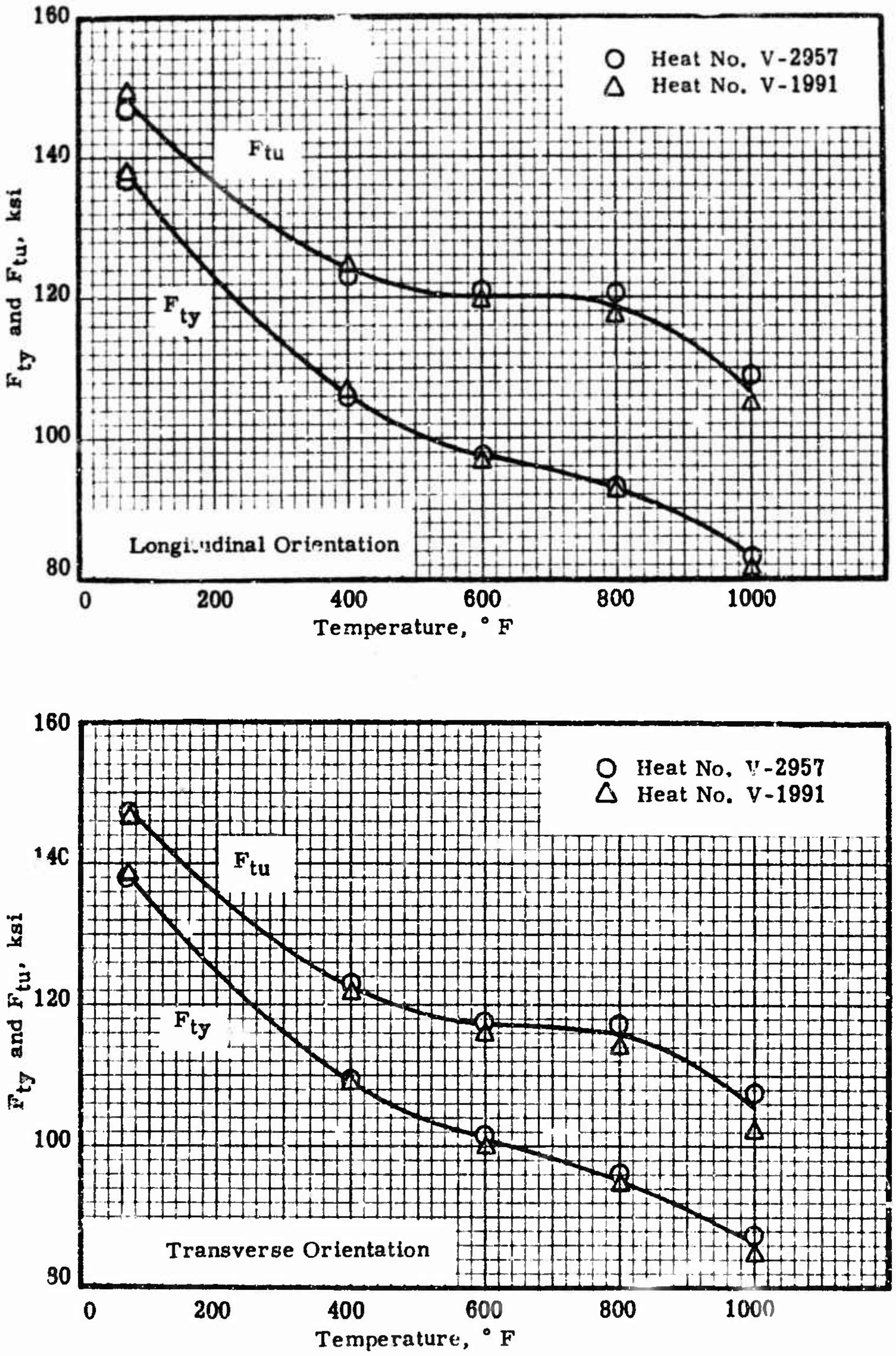
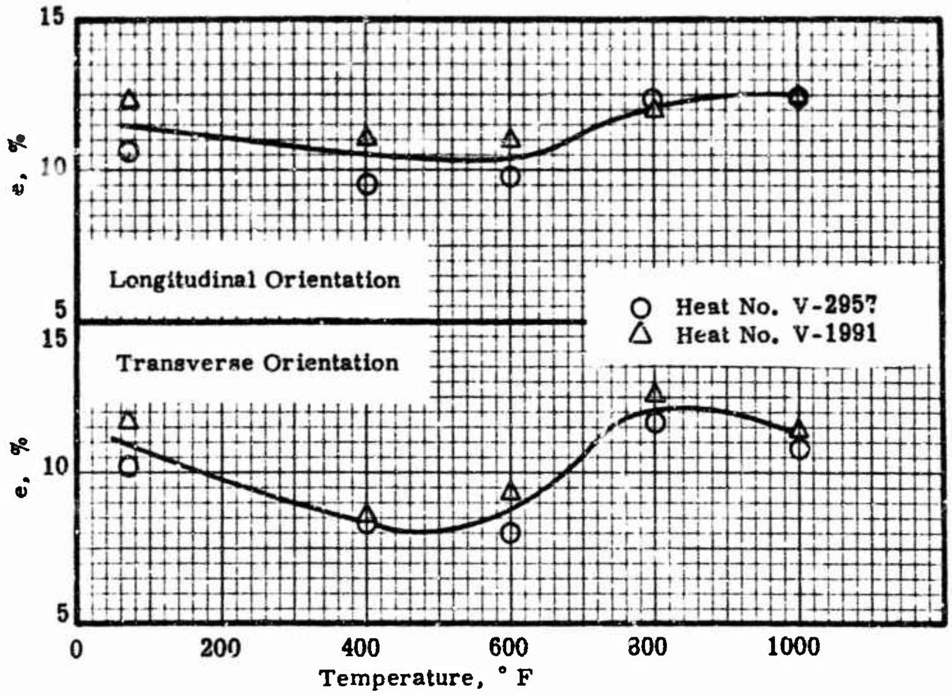


Figure 30. The 0.2%-Offset Yield Strength and Tensile Strength of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet in the Longitudinal and Transverse Orientations.

Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.



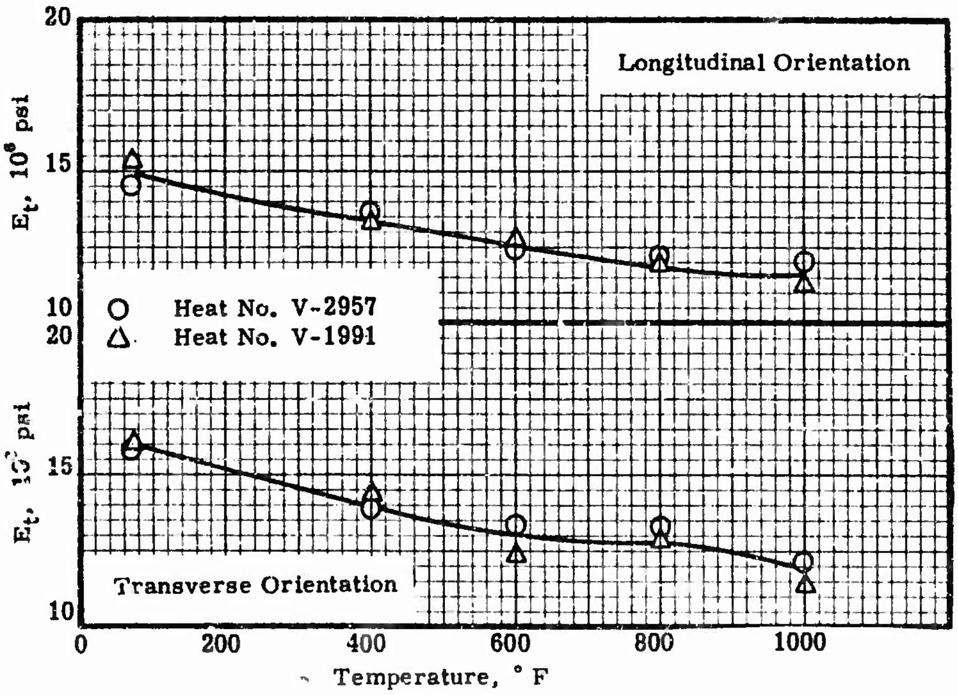


Figure 31. The Percent Elongation and Modulus of Elasticity in Tension of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet in the Longitudinal and Transverse Orientations.

Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. +
1400° F, 1/4 hr, A.C.

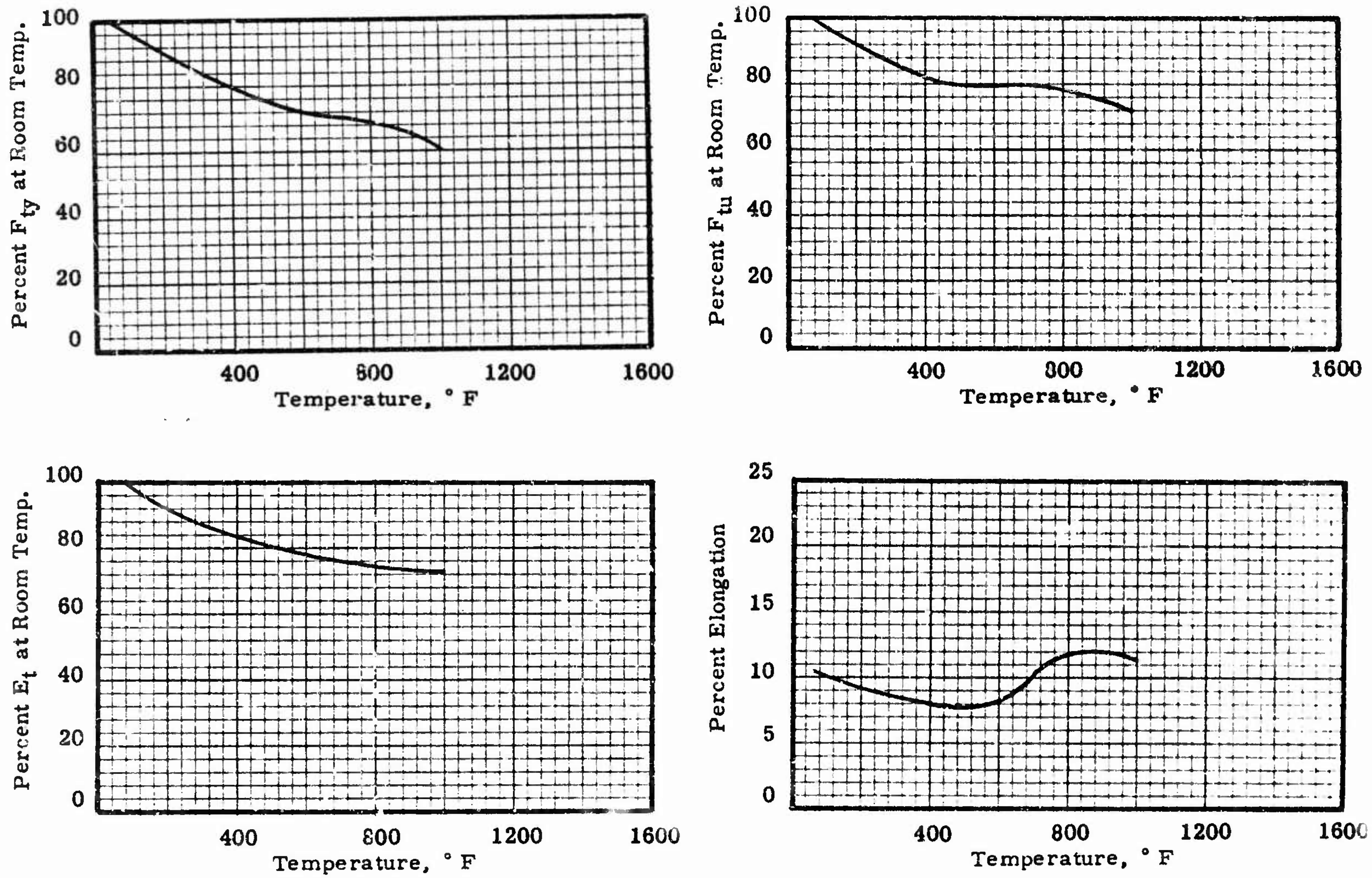
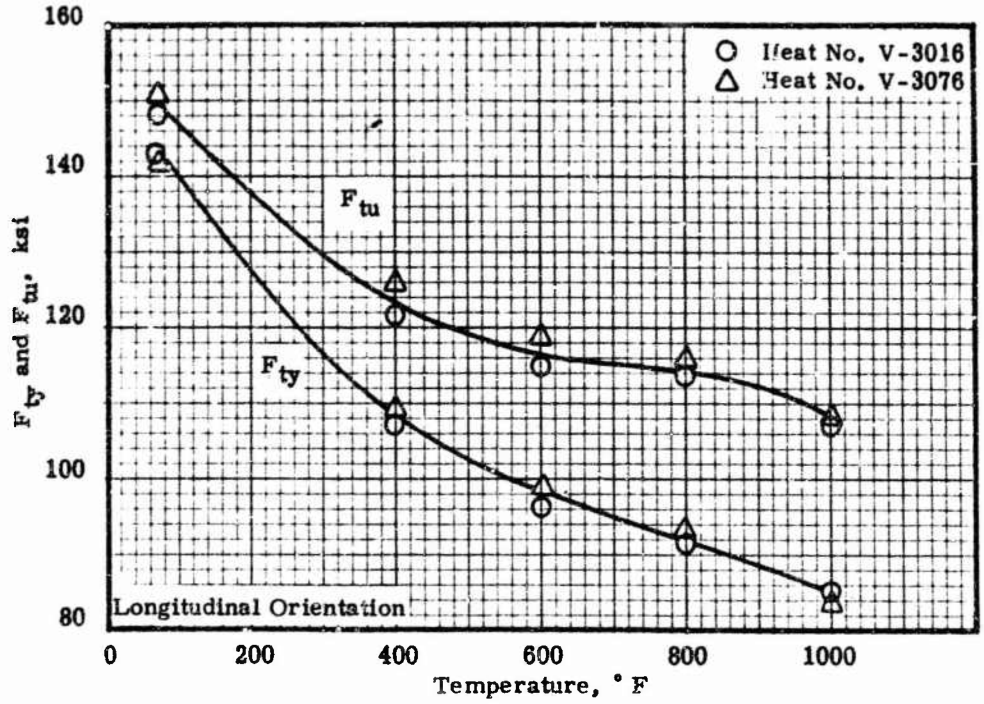


Figure 32. The Effect of Temperature on the Tensile Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet

Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.



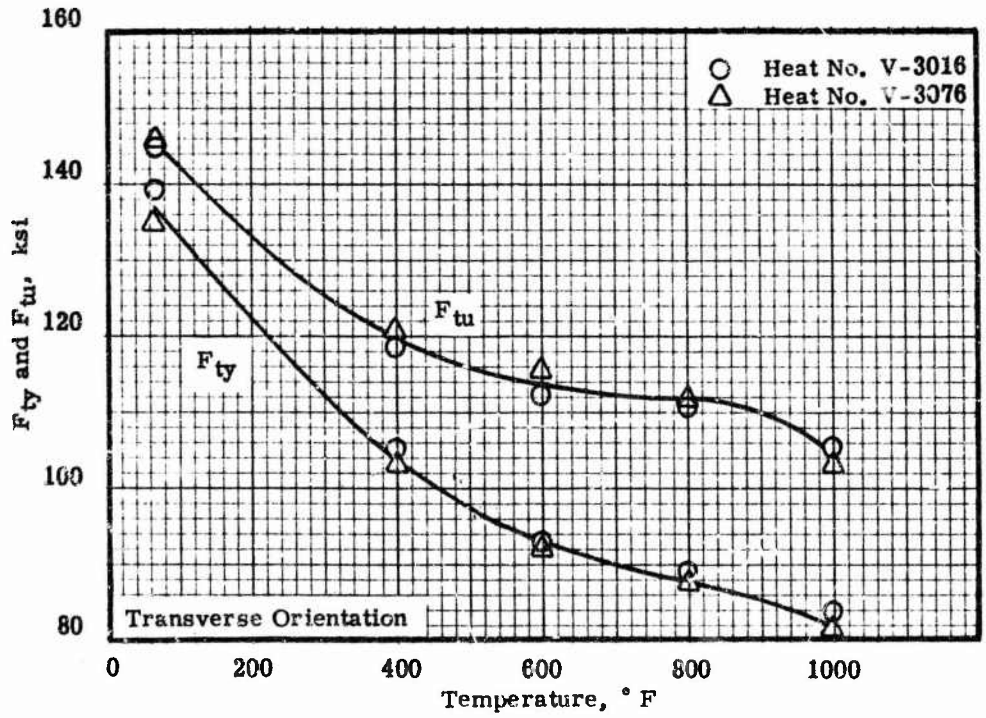


Figure 33. The 0.2%-Offset Yield Strength and Tensile Strength of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet At Different Temperatures.

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

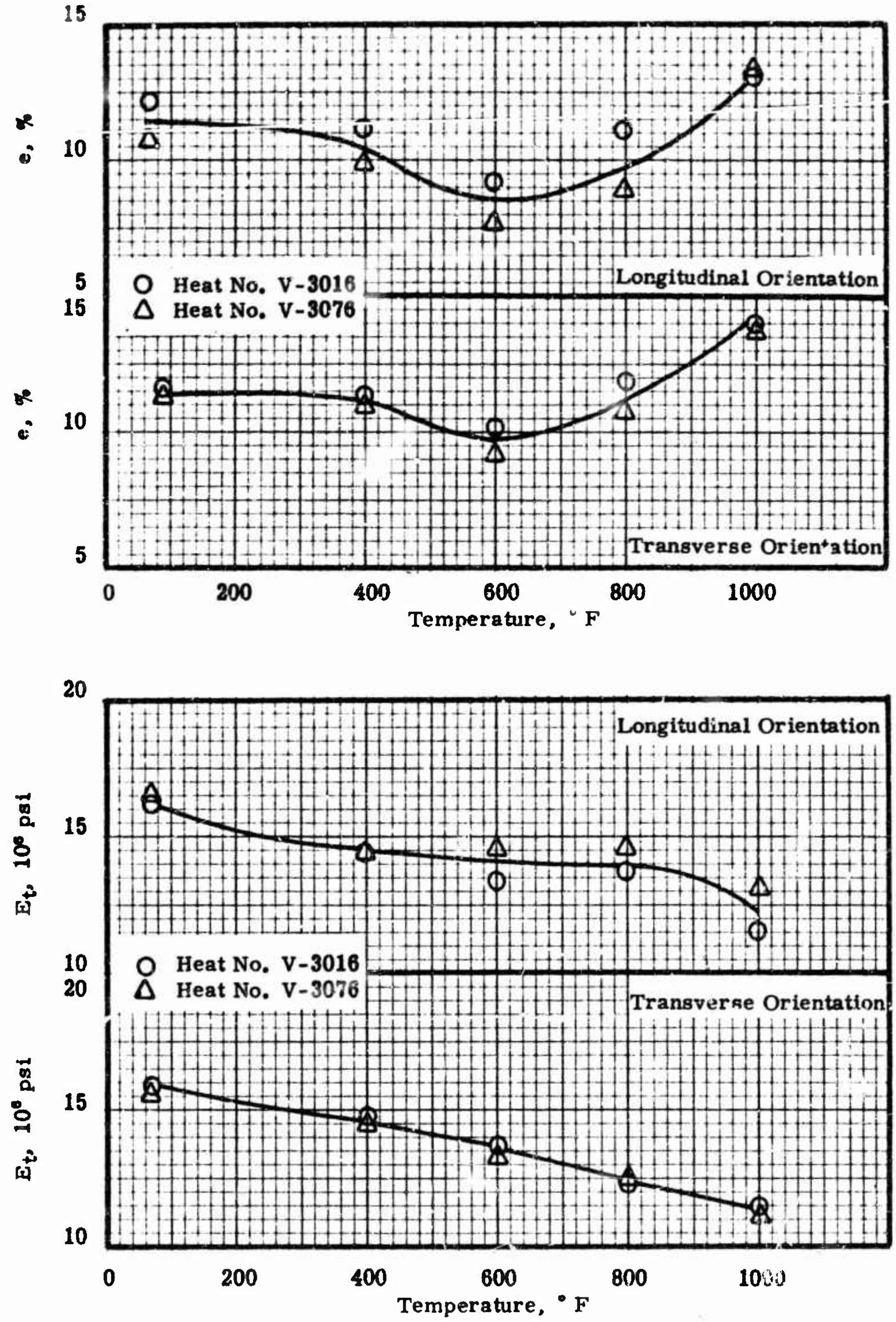


Figure 34. The Percent Elongation and Modulus of Elasticity in Tension of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures.

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C., 1450° F, 1/4 hr, A.C.

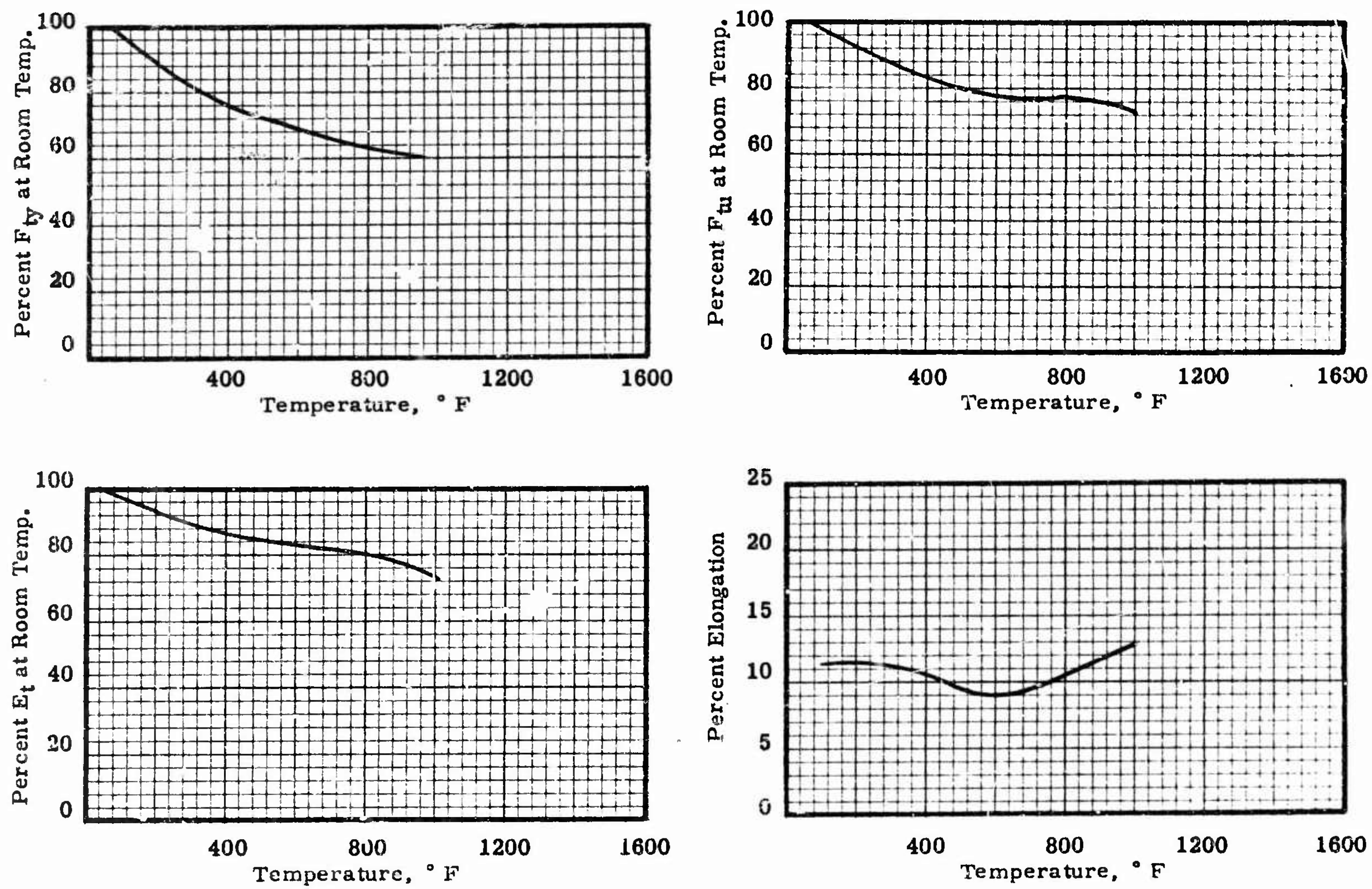


Figure 35. The Effect of Temperature on the Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet

Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C

Table 12

Precision Modulus of Elasticity of the Sheet Alloys in the Longitudinal Direction at Room Temperature[a,b,c]

Alloy	Modulus of Elasticity, 10^6 psi
Ti-5Al-5Sn-5Zr	15.929
Ti-5Al-5Sn-5Zr-1Mo-1V	16.080
Ti-6Al-2Sn-4Zr-2Mo	16.295

a Sheet thickness: 40 mil

b Heat Nos: Ti-5Al-5Sn-5Zr, D-8060
Ti-5Al-5Sn-5Zr-1Mo-1V, V-2957
Ti-6Al-2Sn-4Zr-2Mo, V-3016

c Heat treatments:
Ti-5Al-5Sn-4Zr, 1650° F, 1/2 hr, A.C.
Ti-5Al-5Sn-5Zr-1Mo-1V, 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
Ti-6Al-2Sn-4Zr-2Mo, 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

Table 13

Summary of Averaged Notched Tensile Strength of the Sheet Alloys[a, b, c, d]

Alloy	Temperature, °F 70	400	800
Ti-5Al-5Sn-5Zr	166.8	121.1	105.4
Ti-5Al-5Sn-5Zr-1Mo-1V	165.4	131.5	130.9
Ti-6Al-2Sn-4Zr-2Mo	170.1	137.7	132.5

a Thickness: 40 mil

b Heat treatment:

Ti-5Al-5Sn-5Zr, 1650° F, 1/2 hr, A.C.
Ti-5Al-5Sn-5Zr-1Mo-1V, 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
Ti-6Al-2Sn-4Zr-2Mo, 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

c Notched 45°, 0.025 in. radius, 0.375 minimum width to produce $K_t = 3$.

d All tests in longitudinal direction.

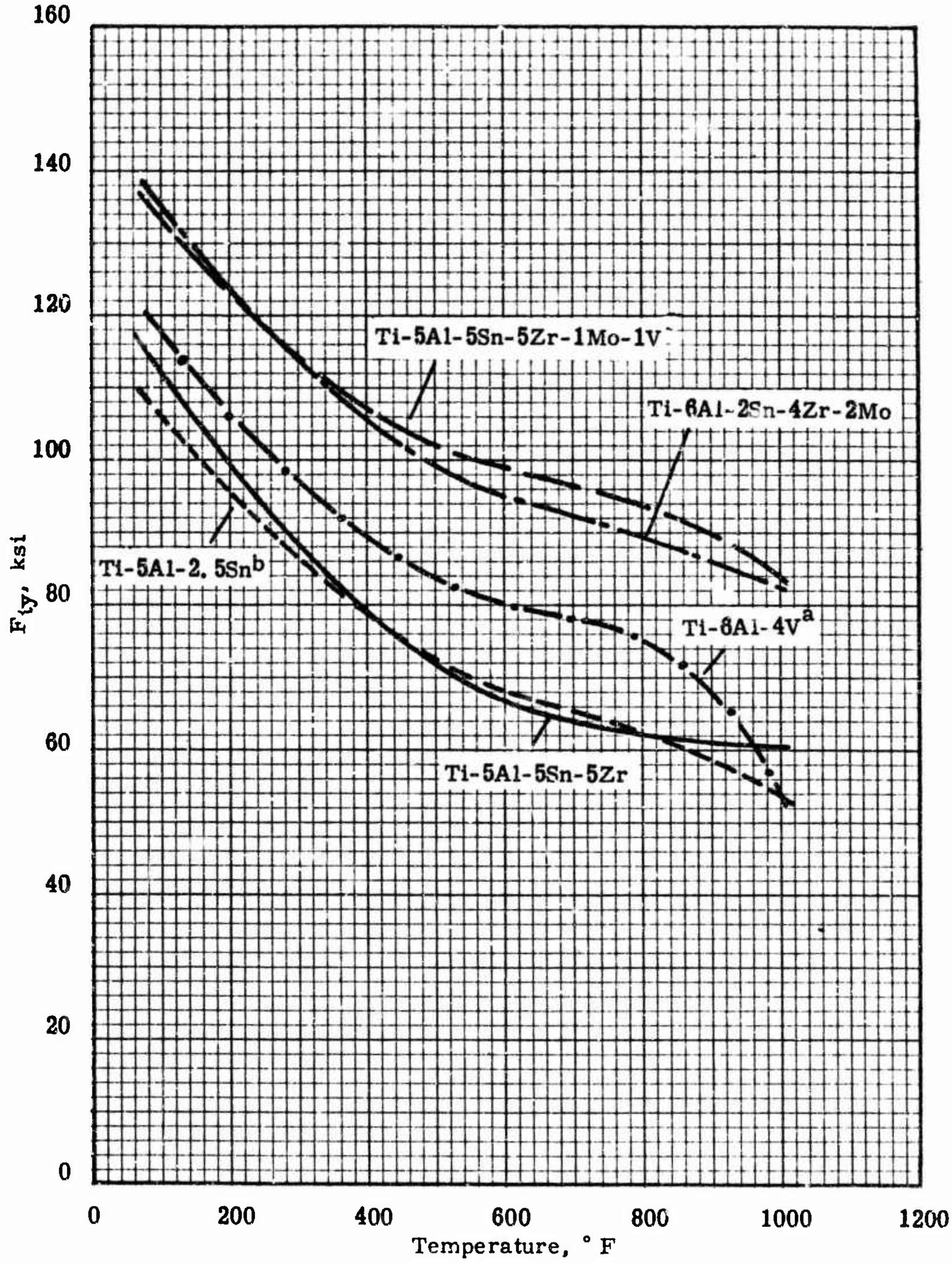


Figure 36. Comparison of the 0.2%-Offset Yield Strength of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for other Titanium Alloys.

Referenced data
a - MILHDBK 5, p 5.4.6.2.1 (b)
b - MILHDBK 5, p 5.3.1.2.1 (b)

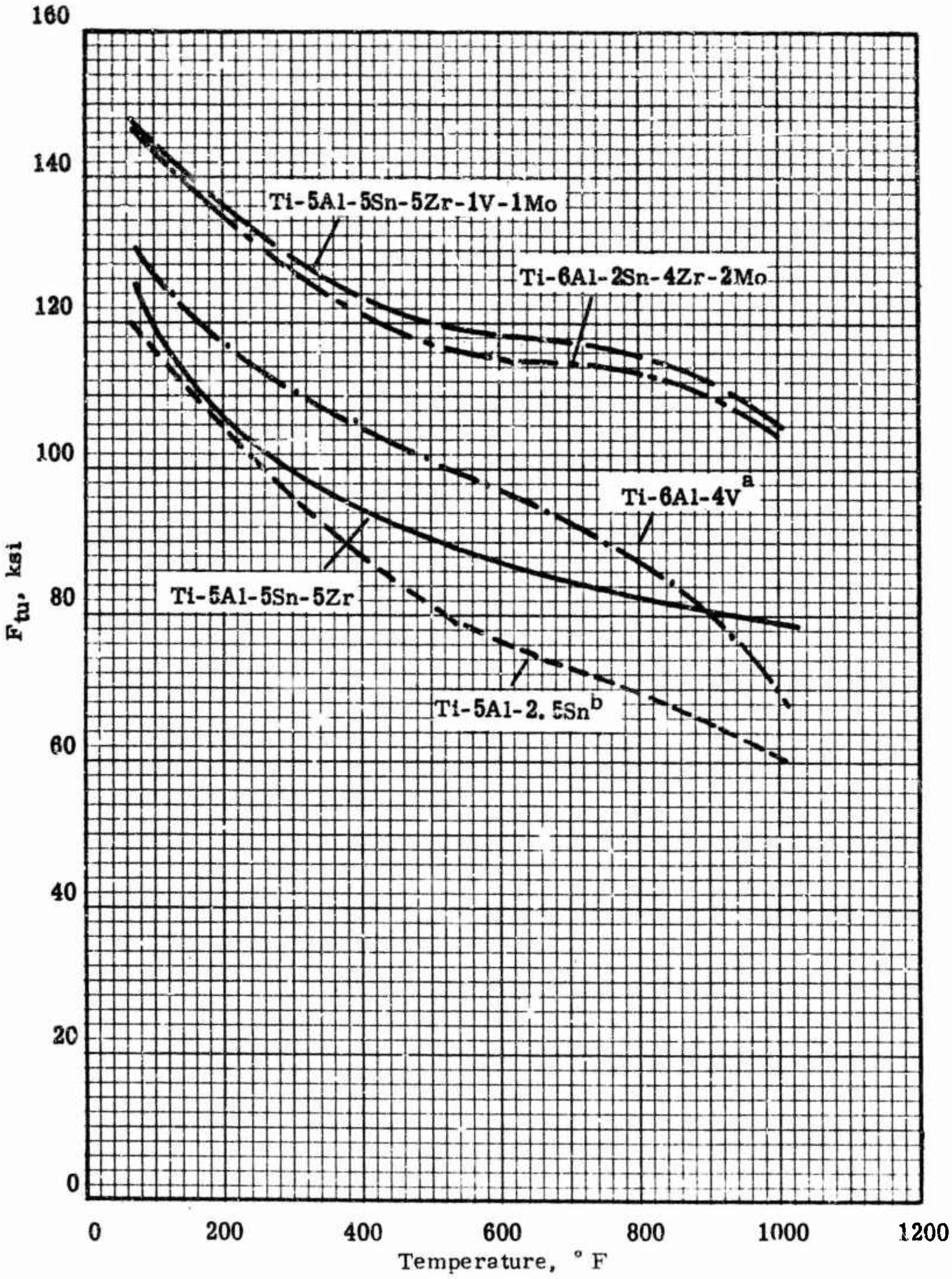
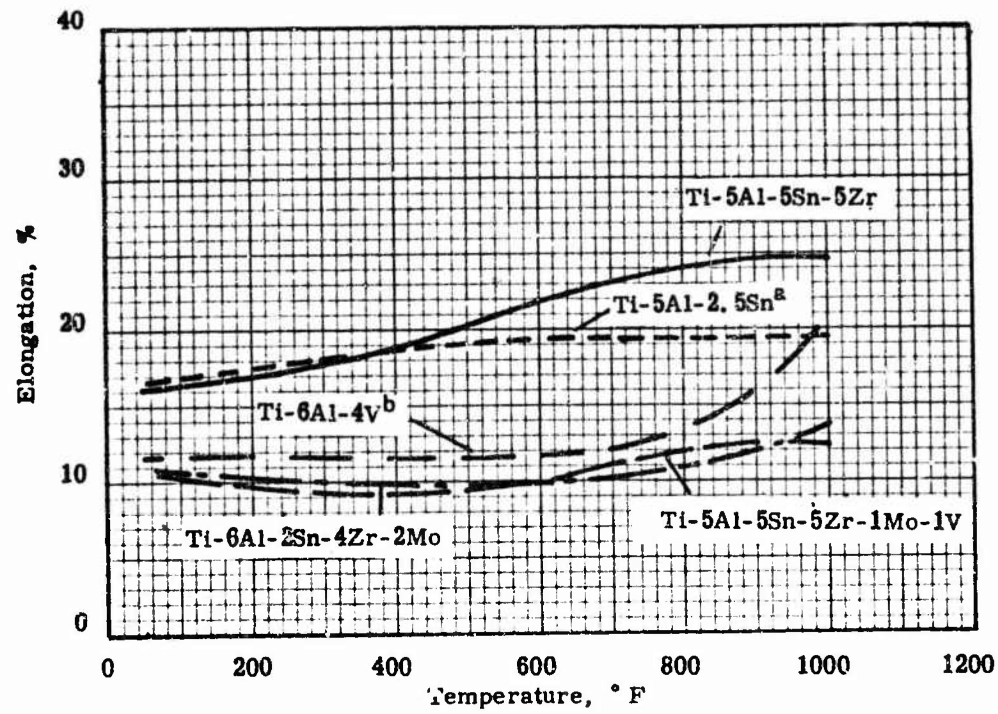


Figure 37. Comparison of the Ultimate Tensile Strength of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data
a - MILHDBK 5, p 5.4.6.2.1 (a)
b - MILHDBK 5, p 5.3.1.2.1 (a)



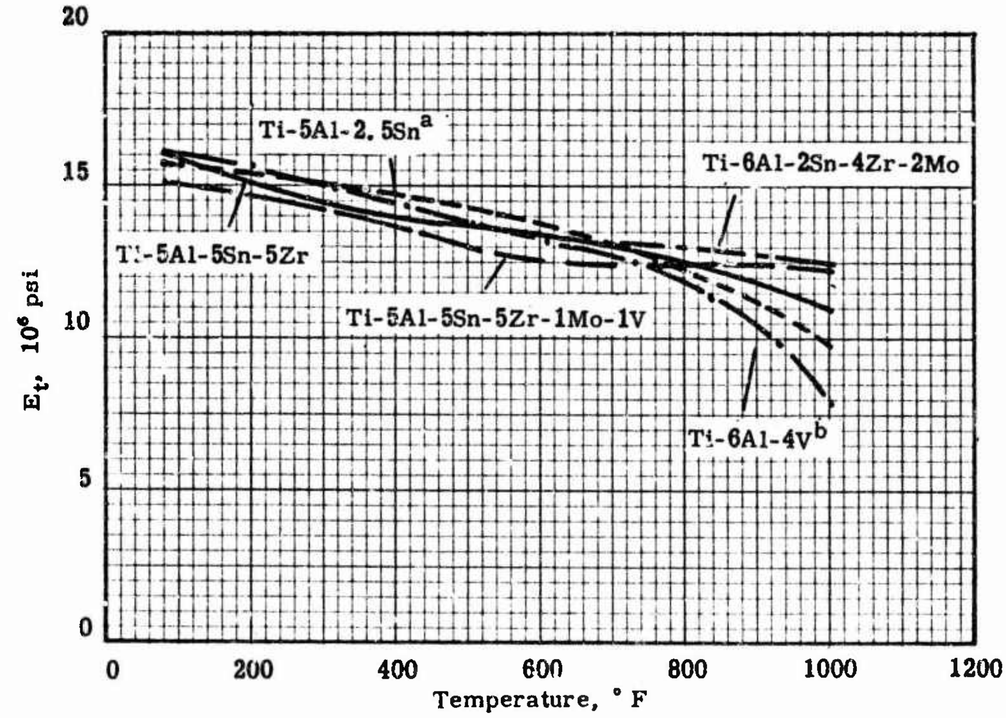


Figure 38. Comparison of Elongation and Modulus of Elasticity in Tension of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data
MILHDBK 5, p 5.3.1.2.4
MILHDBK 5, p 5.4.6.2.4

above 800° F was also lower for the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alloys than for the Ti-6Al-4V alloy. The yield strength of the Ti-5Al-5Sn-5Zr all-alpha alloy was comparable to that of the Ti-5Al-2.5Sn alloy at all test temperatures, but the tensile strength of the Ti-5Al-5Sn-5Zr alloy was higher at the elevated temperatures than for the Ti-5Al-2.5 Sn alloy. Figure 38 shows that the elongation of the higher-strength alpha-beta alloys was generally lower than that of the all-alpha alloys.

Compression

All data for the compression tests are given in the following tables and figures:

Alloy	Figures	Tables[a]
Ti-5Al-5Sn-5Zr	39, 40, 45	14, <u>43</u>
Ti-5Al-5Sn-5Zr-1Mo-1V	41, 42, 45	14, <u>44</u>
Ti-6Al-2Sn-4Zr-2Mo	43, 44, 45	14, <u>45</u>

a Tables with numbers underlined are in Appendix I.

Results of the compression tests in Table 14 and Figures 39 - 44 represent averages of five determinations for each temperature and orientation of the major heat of the sheet alloys. At most temperatures the compressive yield strength was approximately equal to the tensile yield strength for each alloy. The modulus of elasticity in compression was generally slightly lower than the modulus in tension, which is probably due to very slight bending of the compression test specimens even though they were restrained by a special fixture in testing.

Figure 45 shows the comparative yield strength and modulus of elasticity in compression for the three sheet alloys evaluated in this program, and similar data for an all-alpha alloy, Ti-5Al-2.5Sn, and an alpha-beta alloy, Ti-6Al-4V. The compressive yield strength of the alpha-beta alloys (Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo) was higher than the compressive strength of the Ti-6Al-4V alloy selected for comparison. The compressive yield strength of the all-alpha Ti-5Al-5Sn-5Zr alloy was slightly lower than that for the Ti-5Al-2.5Sn alloy. The comparative modulus-of-elasticity data in Figure 45 shows that the values for the three sheet alloys evaluated in this program were lower than for the reference alloys. However, since MIL-HDBK-5[6], from which the referenced data were obtained, does not differentiate between tensile and compressive moduli, the comparative curves in Fig. 45 would be in closer agreement if an average value of the tensile and compressive moduii were shown instead of only the modulus in compression.

Table 14

Summary of Averages and Standard Deviations for the Compression Properties at Different Temperatures of Three Titanium Alloys in the Form of Forty-Mil Sheet

Ti-5Al-5Sn-5Zr (Heat No. D-8060)

Temp	Longitudinal				Transverse			
	F_{cy}, ksi		E_c, 10^6, psi		F_{cy}, ksi		E_c, 10^6 psi	
°F	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	119.0	1.9	14.4	0.3	125.8	1.6	15.1	0.2
400	80.2	0.5	12.0	0.3	82.3	0.5	12.8	0.1
600	66.7	1.2	10.9	0.8	68.4	0.8	12.1	0.3
800	60.3	1.2	10.6	0.3	62.8	0.4	11.6	0.3
1000	58.0	0.8	9.7	0.2	59.3	0.9	10.3	0.2

Heat treatment: 1650° F, 2 hr, A.C.

Ti-5Al-5Sn-5Zr-1Mo-1V (Heat No. V-2957)

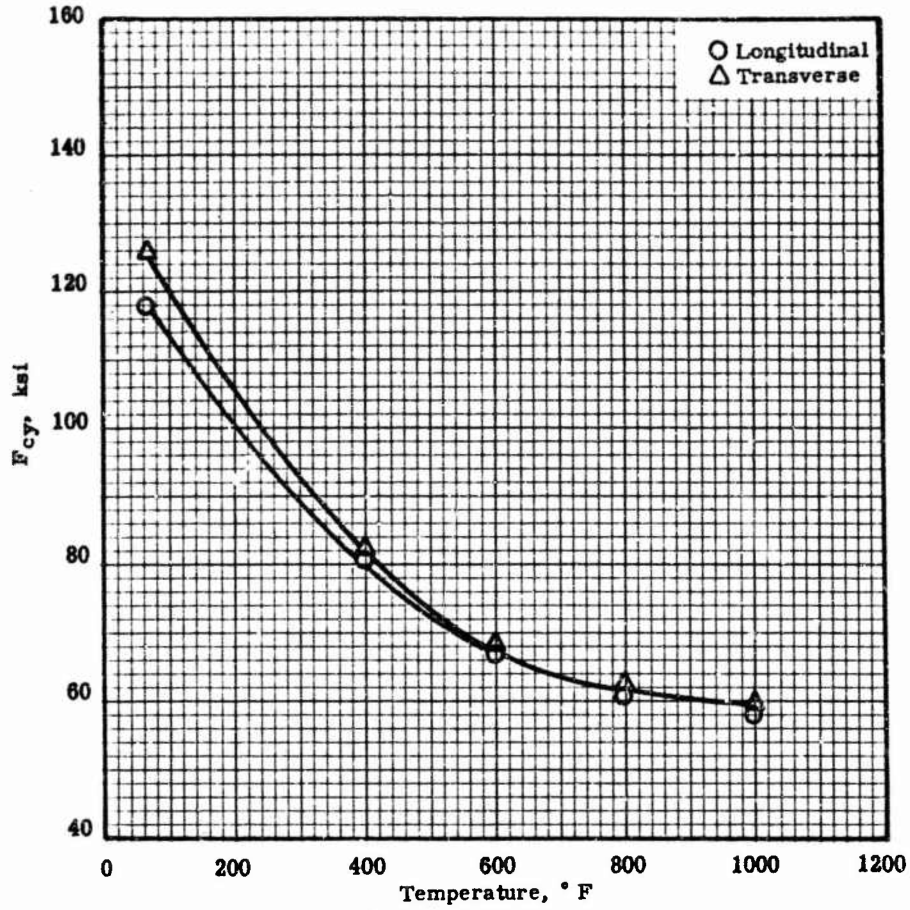
Temp	Longitudinal				Transverse			
	F_{cy}, ksi		E_c, 10^6 psi		F_{cy}, ksi		E_c, 10^6 psi	
°F	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	141.9	2.3	14.3	0.3	154.1	2.4	15.3	0.2
400	103.7	5.5	12.7	0.1	113.7	1.2	13.3	0.5
600	97.8	2.8	11.6	0.3	103.3	1.1	12.2	0.3
800	93.3	1.8	11.1	0.1	99.2	2.1	11.9	0.3
1000	83.8	1.8	10.1	0.3	88.0	1.4	10.6	0.2

Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

Ti-6Al-2Sn-4Zr-2Mo (Heat No. V-3016)

Temp	Longitudinal				Transverse			
	F_{cy}, ksi		E_c, 10^6 psi		F_{cy}, ksi		E_c, 10^6 psi	
°F	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	149.6	4.5	14.3	0.6	144.4	4.7	14.5	0.3
400	111.3	4.2	12.7	0.3	105.9	2.3	12.5	0.3
600	99.7	3.9	12.1	0.2	95.5	4.1	11.4	0.2
800	96.5	5.9	11.3	0.6	88.0	2.6	11.0	0.3
1000	85.3	4.4	10.6	0.5	82.3	3.2	10.2	0.2

Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



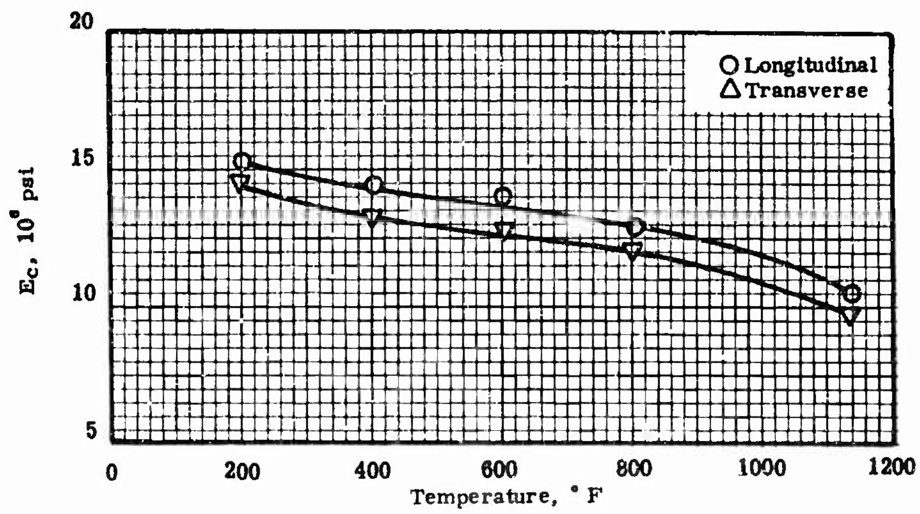
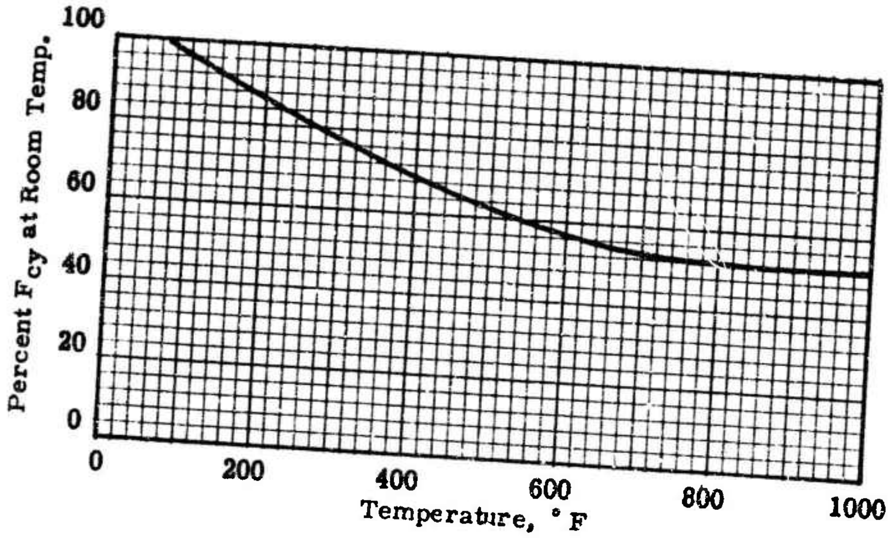


Figure 39. The 0.2%-Offset-Yield Strength and Modulus of Elasticity in Compression of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures.

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.



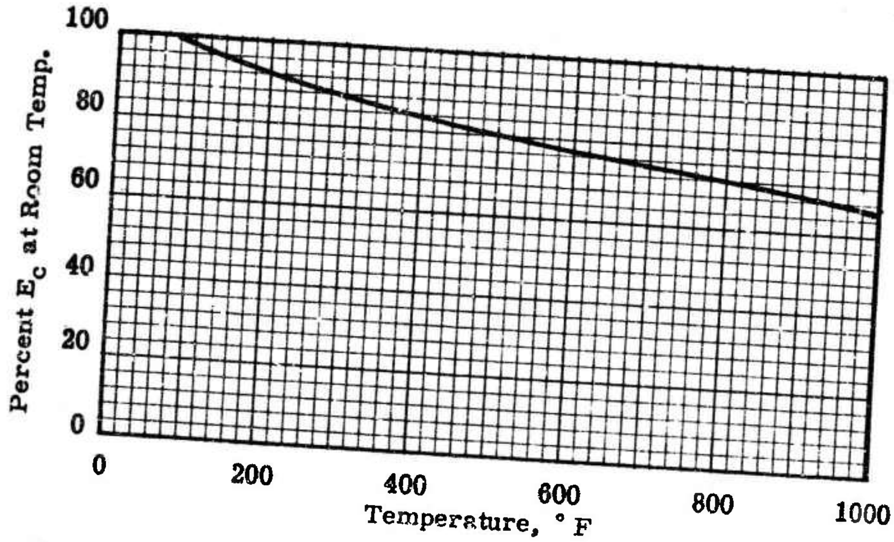


Figure 40. Effect of Temperature on the Compressive Properties of Ti-5Al-5Sn-5Zr Alloy Sheet.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

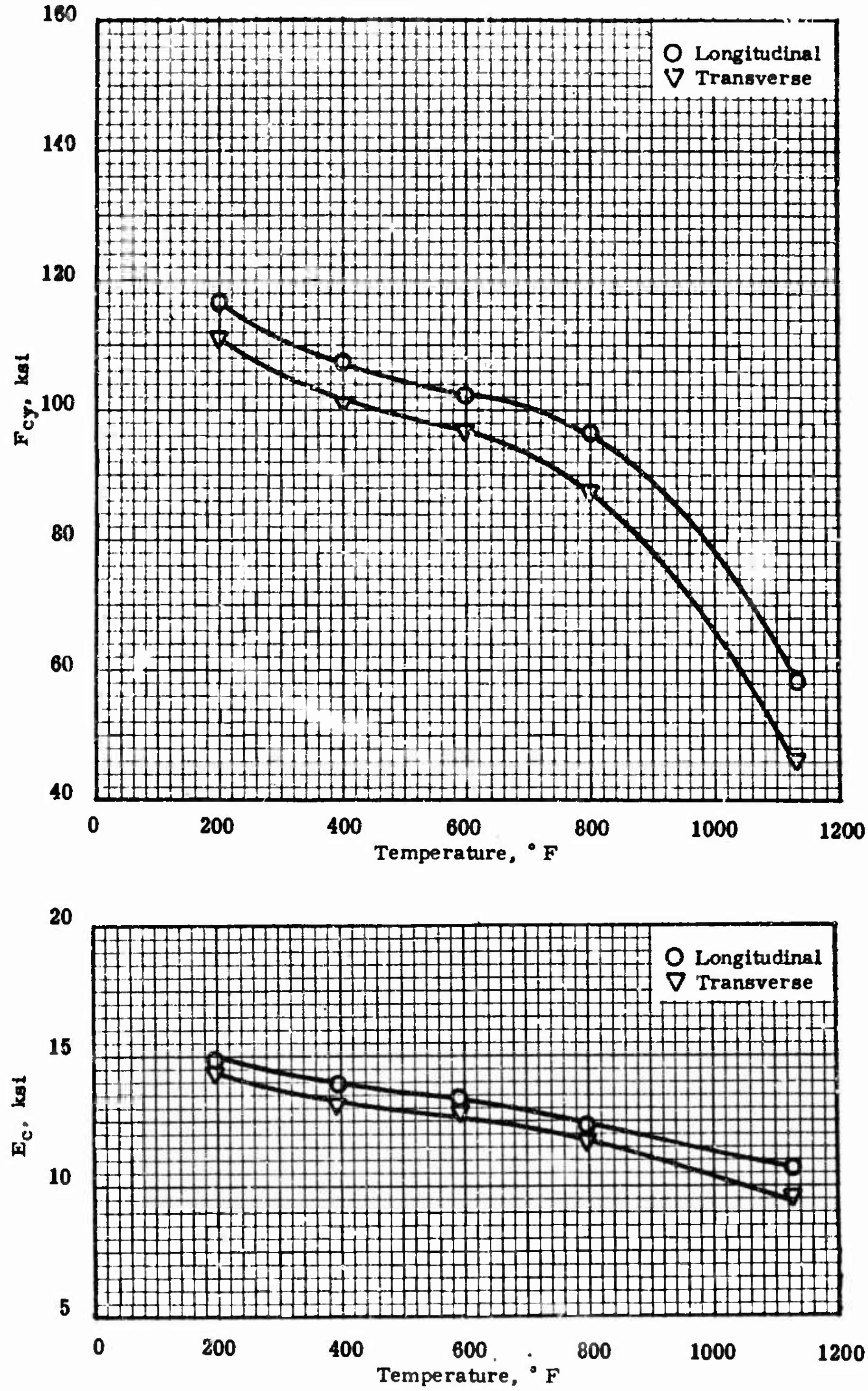


Figure 41. The 0.2%-Offset Yield Strength and Modulus of Elasticity in Compression of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

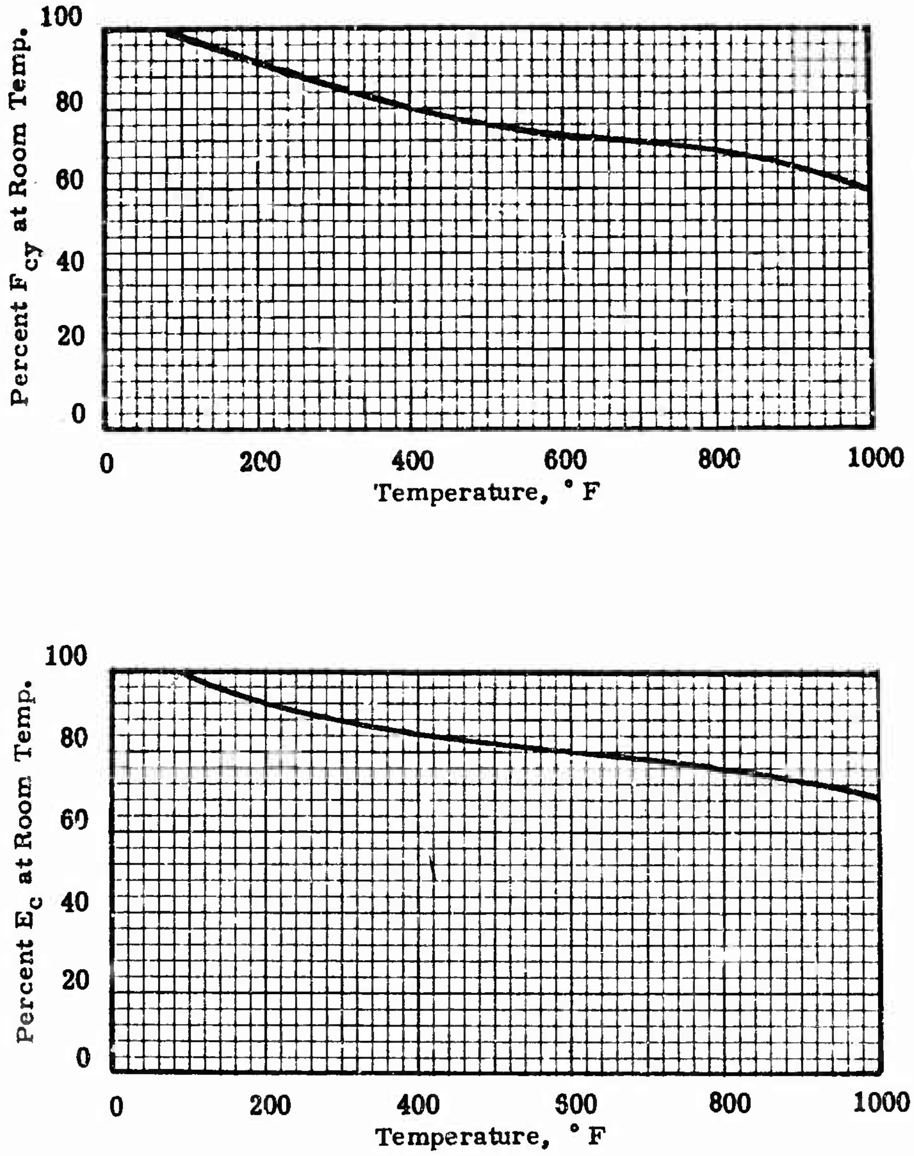


Figure 42. Effect of Temperature on the Compressive Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

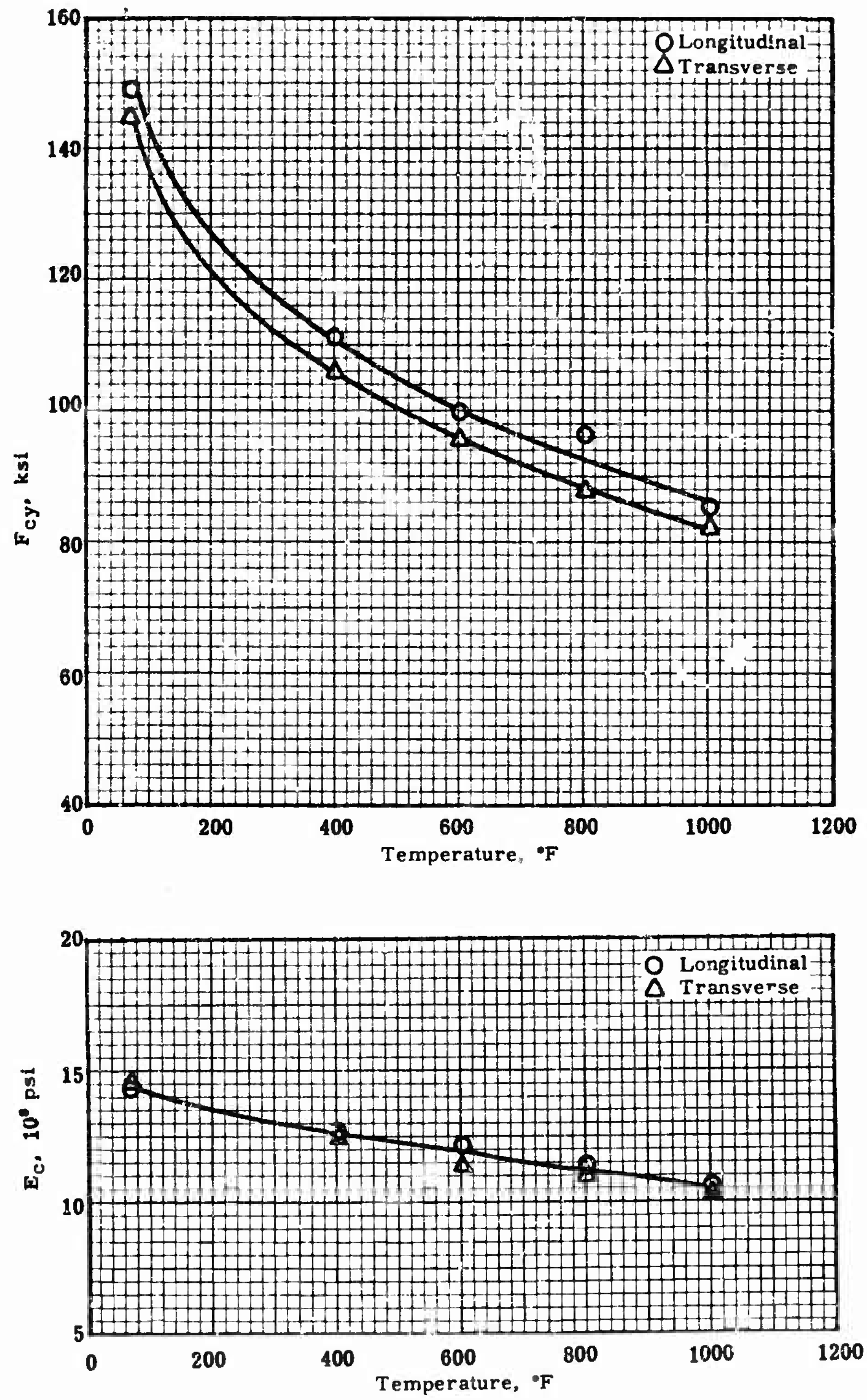
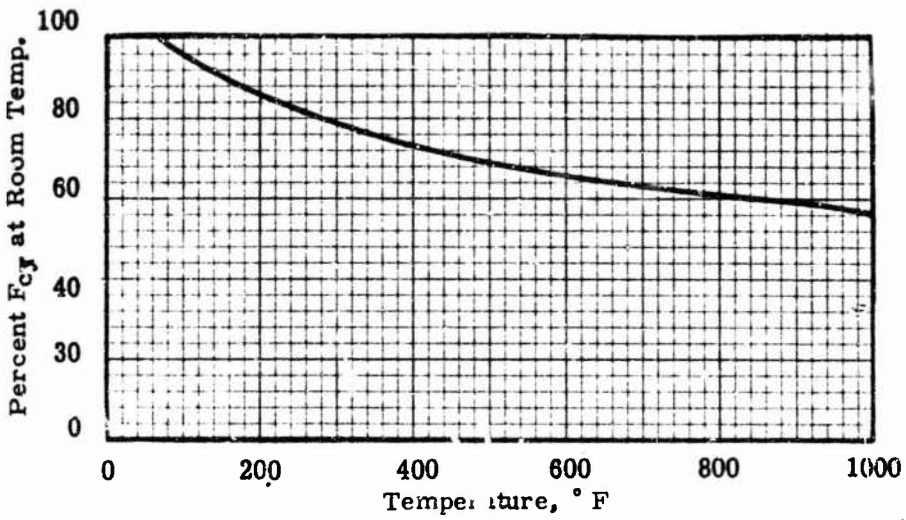


Figure 43. The 0.2%-Offset Yield Strength and Modulus of Elasticity in Compression of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr. A. C. + 1450°F, 1/4 hr, A. C.



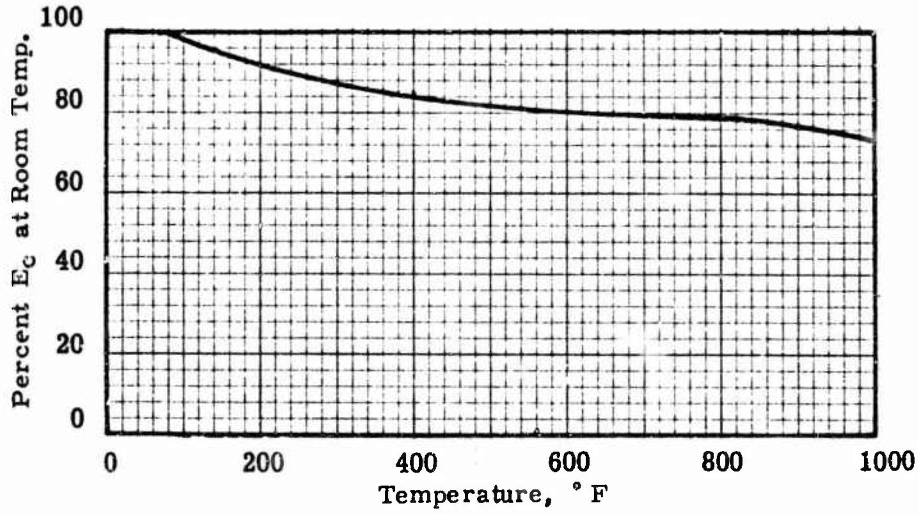
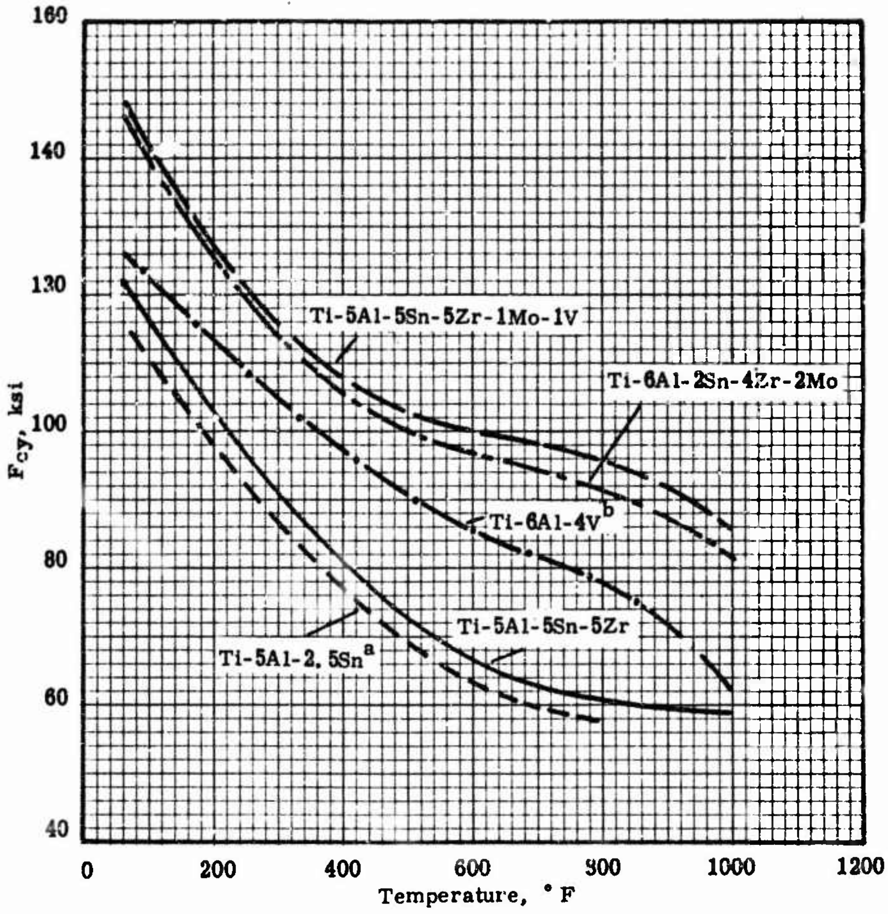


Figure 44. Effect of Temperature on the Compressive Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



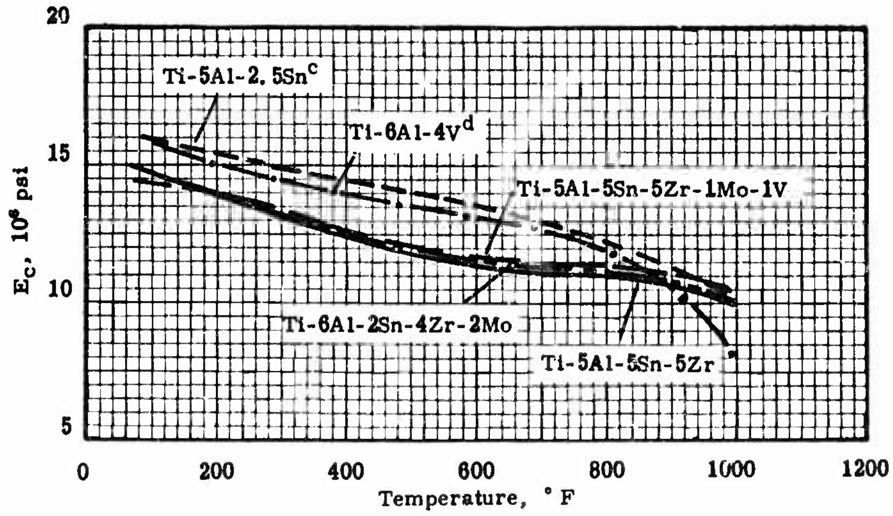


Figure 45. Comparison of the Compressive Properties of Titanium Alloy Sheet Evaluated in this Program with Data from the Literature for other Titanium Alloys.

Referenced Data
a - MILHDBK 5, p 5.3.1.2.2 (a)
b - MILHDBK 5, p 5.4.6.2.2 (a)
c - MILHDBK 5, p 5.3.1.2.4
d - MILHDBK 5, p 5.4.6.2.4

Bearing

Results of bearing tests on the sheet alloys are given in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	46, 47, 52, 53	15, 46
Ti-5Al-5Sn-5Zr-1Mo-1V	48, 49, 52, 53	16, 47
Ti-6Al-2Sn-4Zr-2Mo	50, 51, 52, 53	17, 48

Tables with numbers underlined are in Appendix I.

The data tabulated in Tables 15 - 17 and plotted in Figures 46 - 51 represent averages of three determinations for each temperature, orientation and e/D ratio combination. The bearing yield strength in the longitudinal and transverse orientations were generally comparable at each e/D ratio strength level. However, the bearing ultimate strength was generally higher in the transverse direction than in the longitudinal direction for the Ti-5Al-5Sn-5Zr and the Ti-5Al-5Sn-5Zr-1Mo-1V alloys and equal in both orientations for the Ti-6Al-2Sn-4Zr-2Mo alloy.

Comparative plots of the bearing properties for the three sheet alloys and the Ti-5Al-2.5Sn and Ti-6Al-4V alloys are shown in Figures 52 and 53 in which the bearing strength of the three alloys evaluated in this program is represented by the average for the two orientations. At both e/D ratios the bearing strength of the Ti-5Al-5Sn-5Zr-1Mo-1V and the Ti-6Al-2Sn-4Zr-2Mo alloys are comparable at all test temperatures and exceed the bearing strength of the comparative alloy, Ti-6Al-4V. The bearing strength of the Ti-5Al-5Sn-5Zr is greater at all temperatures than for the Ti-5Al-2.5Sn all-alpha alloy and approximately equal to the Ti-6Al-4V alloy.

Shear

Data for all the shear tests on the sheet alloys appear in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	54, 57, 58	18, 49
Ti-5Al-5Sn-5Zr-1Mo-1V	55, 57, 58	18, 50
Ti-6Al-2Sn-4Zr-2Mo	56, 57, 58	18, 51

Tables with numbers underlined are in Appendix I.

Table 15

Averaged Bearing Properties of the Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures[a, b, c, d]

Temp, °F	Orientation	e/D = 1.5		e/D = 2.0	
		F_{by}, ksi	F_{bu}, ksi	F_{by}, ksi	F_{bu}, ksi
70	L	180.3	202.2	205.3	251.4
400	L	132.5	156.5	156.2	196.8
600	L	115.9	140.9	142.7	180.7
800	L	107.2	133.5	127.7	171.3
1000	L	102.4	125.3	119.2	163.9
70	T	184.3	218.3	215.9	272.0
400	T	135.2	167.4	162.8	217.4
600	T	118.5	152.0	142.4	198.0
800	T	108.9	143.2	134.1	188.6
1000	T	106.0	137.1	127.1	176.7

a Average of triplicate tests.
b Heat treatment: 1650° F, 1/2 hr, A.C.
c. Sheet thickness: 40 mils
d Heat No. D-8060

Table 16

Averaged Bearing Properties of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures[a, b, c, d]

Temp, °F	Orientation	e/D = 1.5		e/D = 2.0	
		F_{by}, ksi	F_{bu}, ksi	F_{by}, ksi	F_{bu}, ksi
70	L	202.8	220.3	243.1	280.5
400	L	165.7	185.5	199.5	234.9
600	L	160.3	178.4	190.0	221.8
800	L	157.5	171.2	184.1	209.0
1000	L	150.7	173.0	171.7	201.4
70	T	209.7	235.2	270.8	287.2
400	T	171.1	202.2	207.9	233.4
600	T	164.5	195.3	194.6	213.7
800	T	156.9	186.3	194.4	202.7
1000	T	153.1	179.9	183.5	201.4

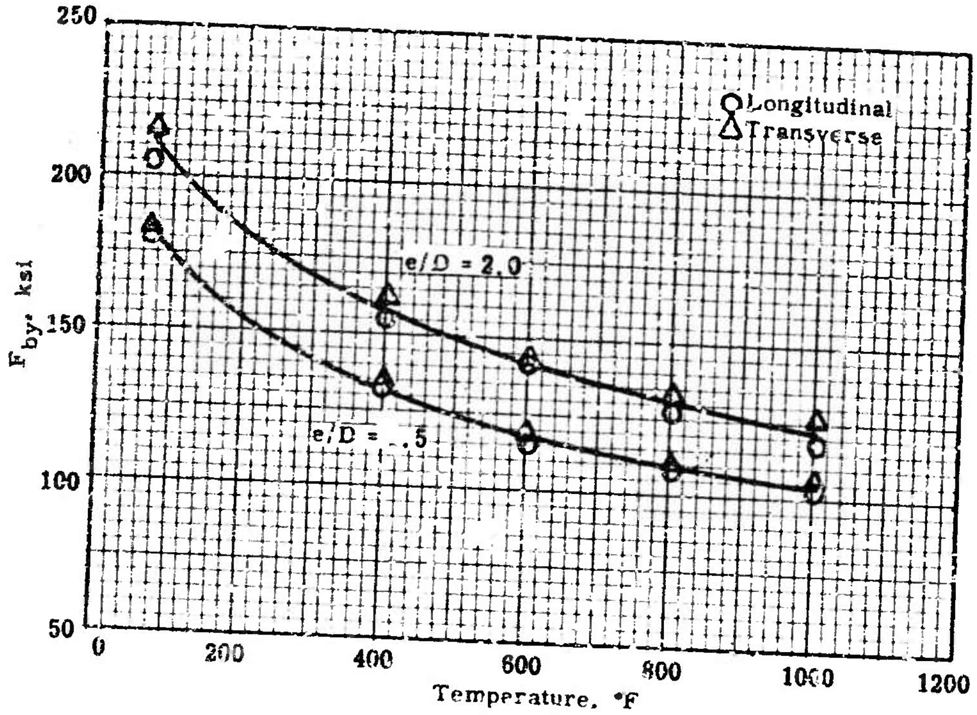
a Average of triplicate tests.
b Heat treatment: 1550° F, 1/2 hr, A.C + 1400° F, 1/4 hr, A.C.
c Sheet thickness: 40 mils
d Heat No. V-2957

Table 17

Averaged Bearing Properties of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures[a, b, c, d]

Temp, °F	Orientation	e/D = 1.5		e/D = 2.0	
		F_{by}, ksi	F_{bu}, ksi	F_{by}, ksi	F_{bu}, ksi
70	L	200.8	234.1	236.9	292.4
400	L	157.9	187.8	193.6	243.3
600	L	146.8	179.3	176.9	225.4
800	L	142.6	174.2	177.3	217.2
1000	L	141.5	165.1	169.2	211.4
70	T	198.6	232.1	237.5	267.8
400	T	160.3	189.8	189.5	240.7
600	T	142.3	172.6	172.3	225.5
800	T	145.5	174.6	171.8	204.4
1000	T	140.8	164.5	167.1	205.1

a Average of triplicate tests.
b Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.
c Sheet thickness: 40 mils
d Heat No. V-3016



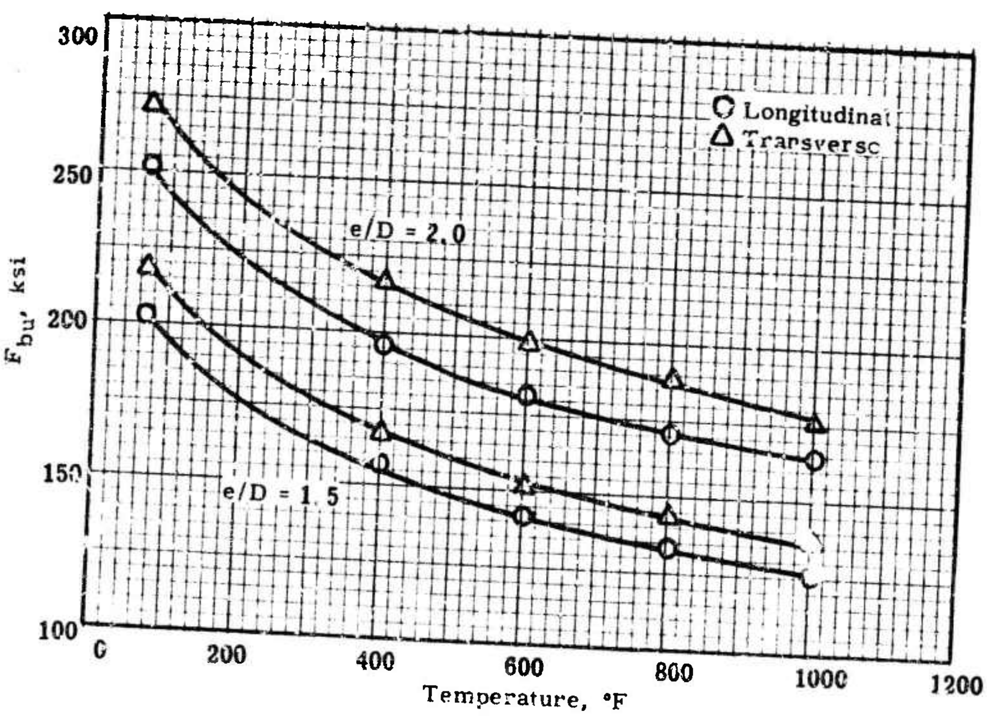


Figure 46. Bearing-Strength Properties of the Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C.

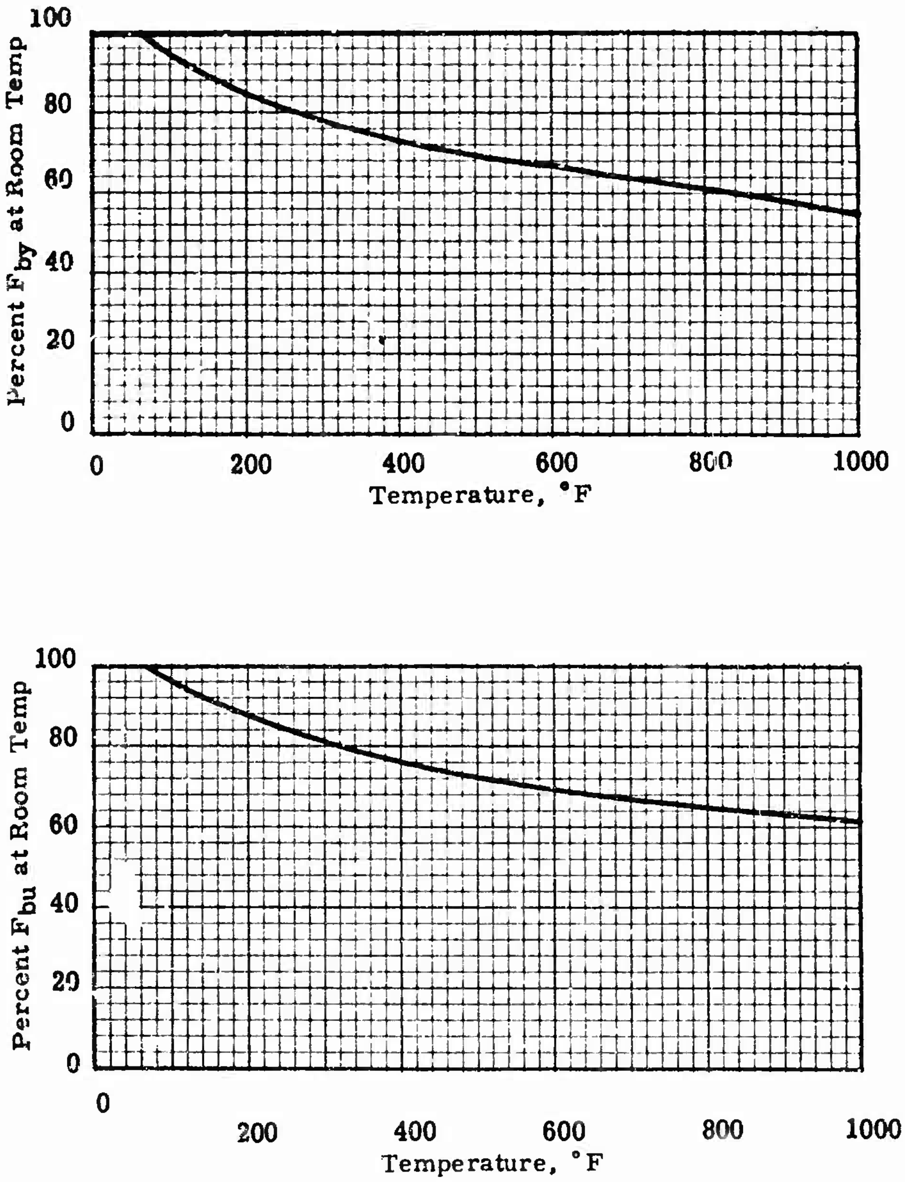


Figure 47. Effect of Temperature on the Bearing Properties of Ti-5Al-5Sn-5Zr Alloy Sheet.

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.

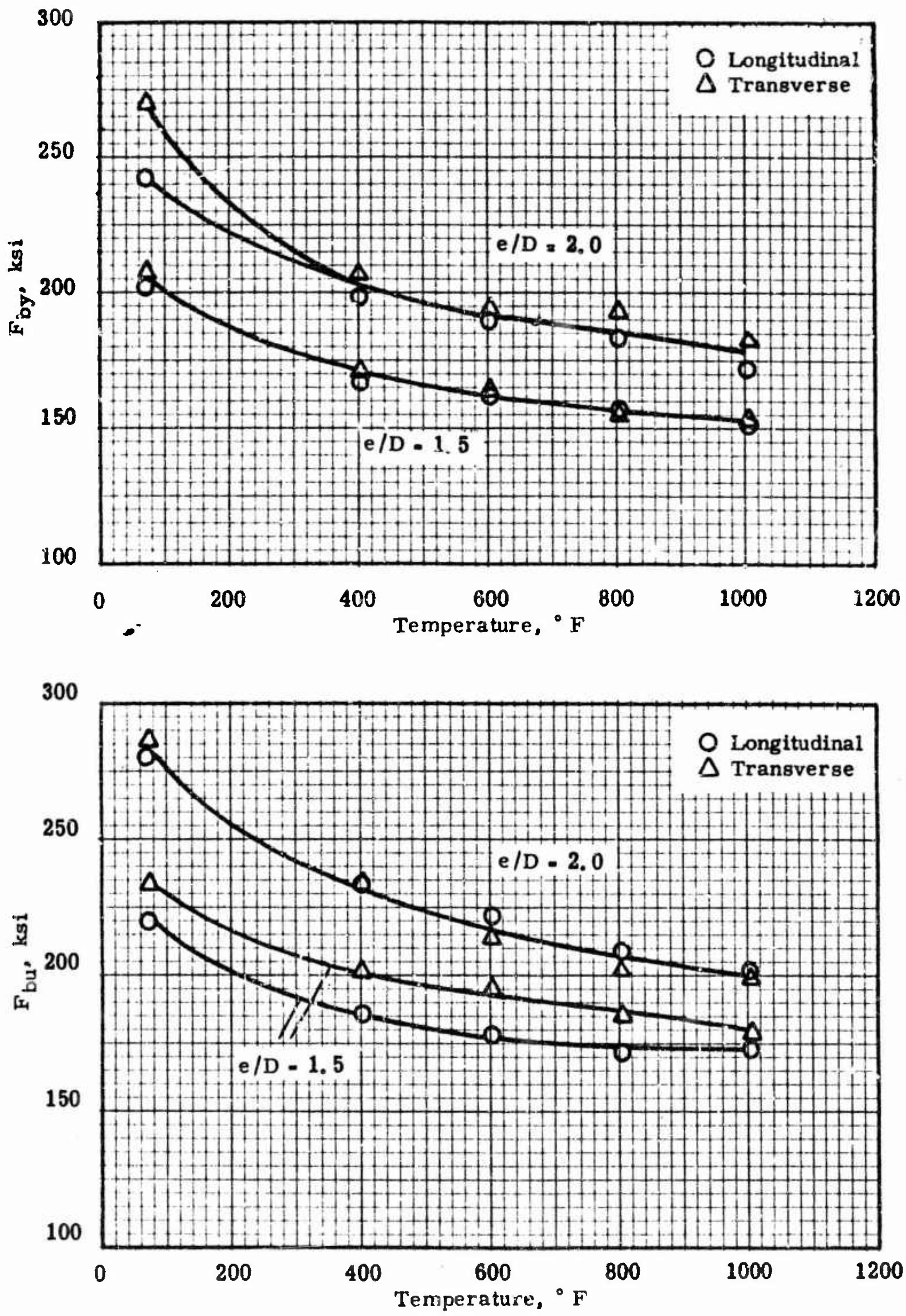
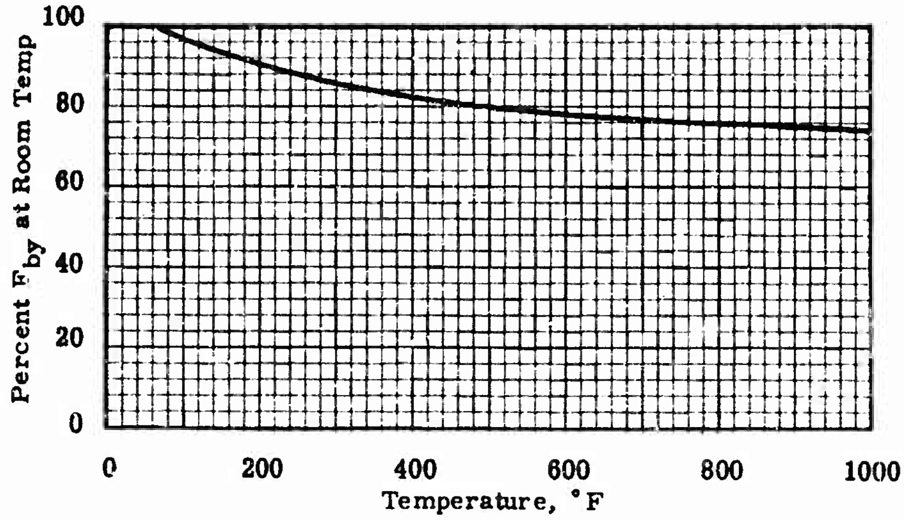


Figure 48. Bearing-Strength Properties of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures.

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.



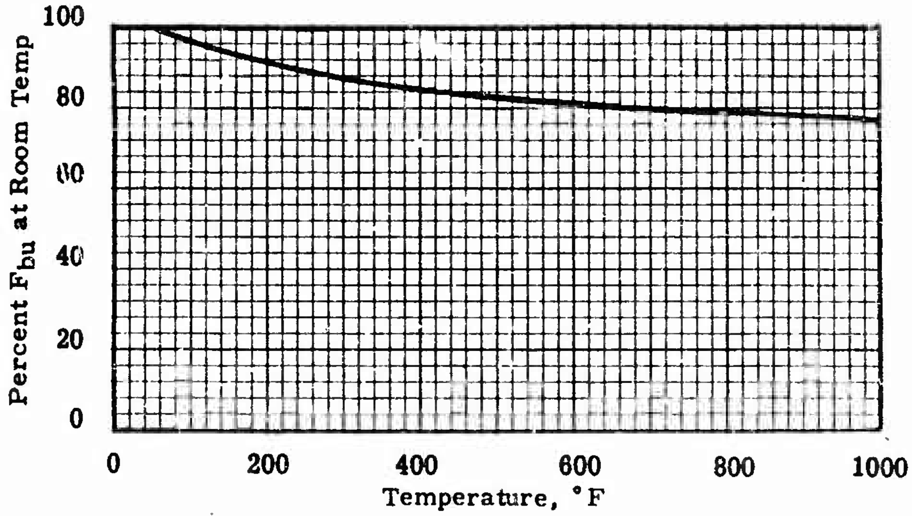


Figure 49. Effect of Temperature on the Bearing Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet.

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

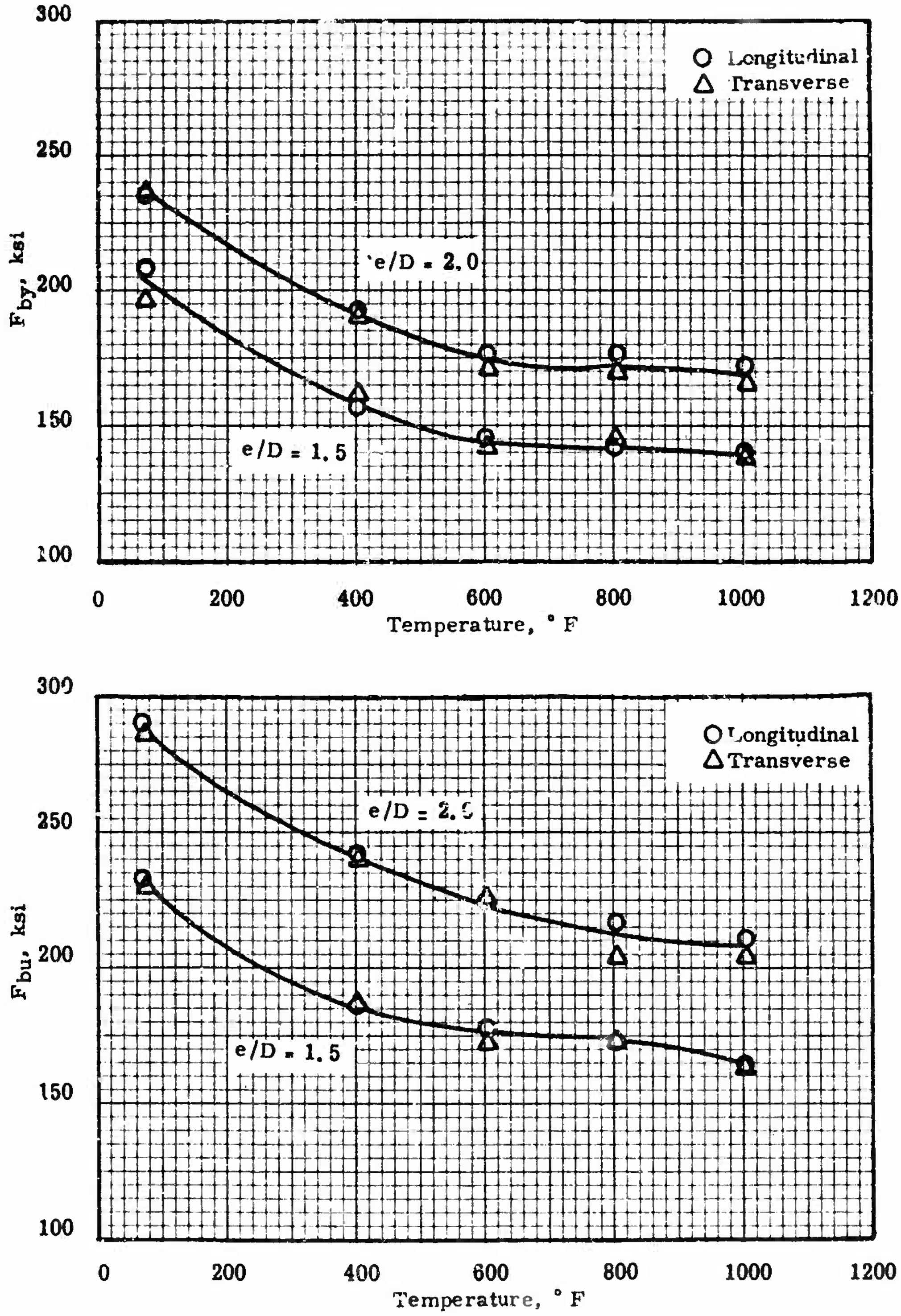
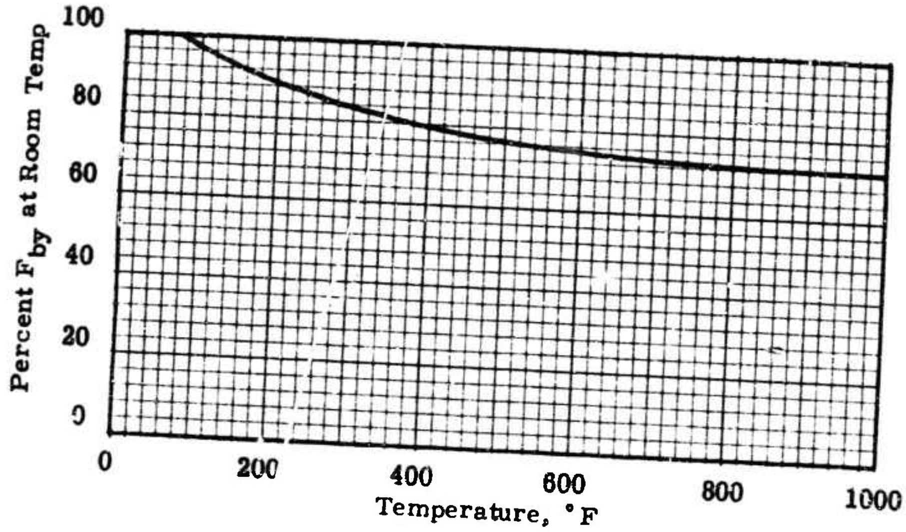


Figure 50. Bearing-Strength Properties of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures.

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



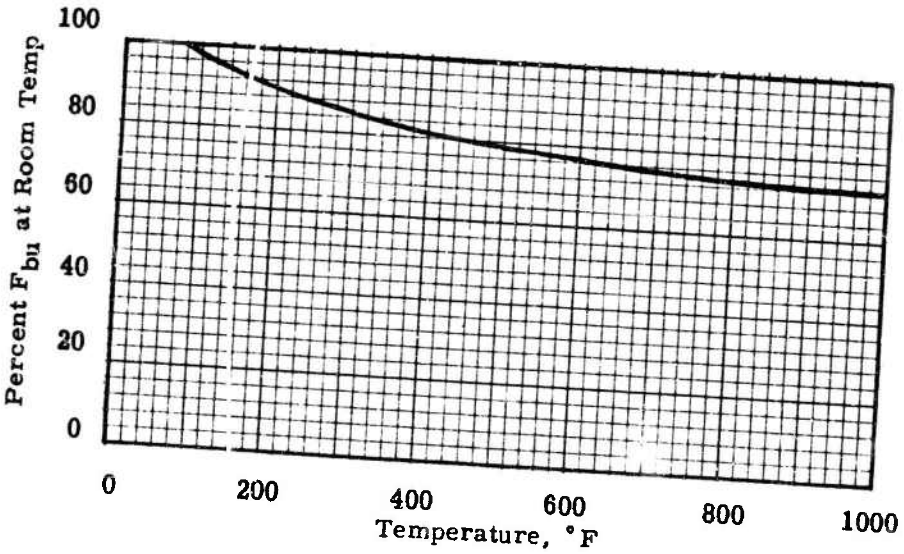


Figure 51. Effect of Temperature on the Bearing Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet.

Heat No. V-3016
Sheet thickness 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

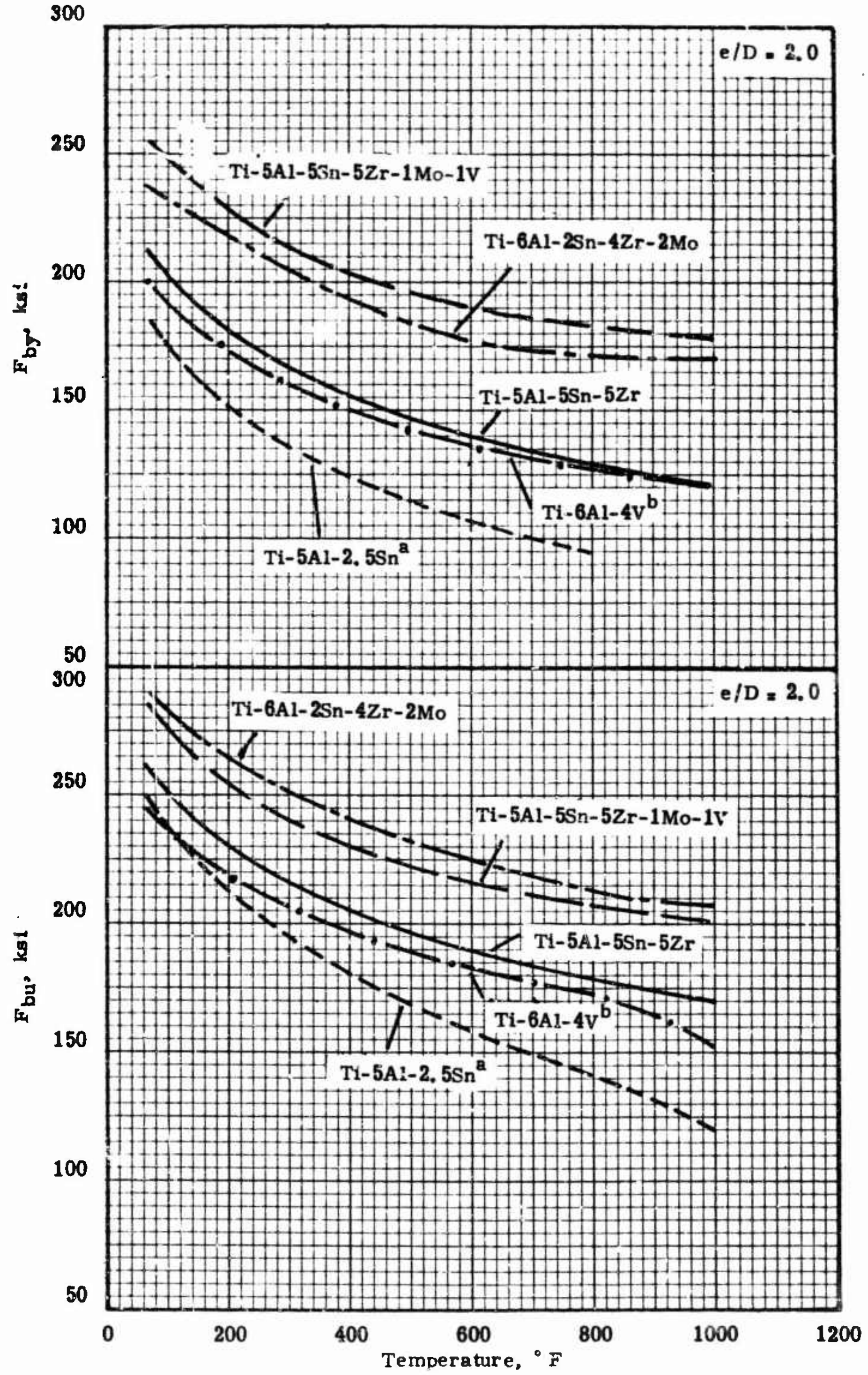


Figure 52. Comparison of the Bearing Strength (e/D = 2.0) of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced data
a - MILHDBK 5, p 5.3.1.2.3 (b)
b - MILHDBK 5, p 5.4.6.2.3 (b)

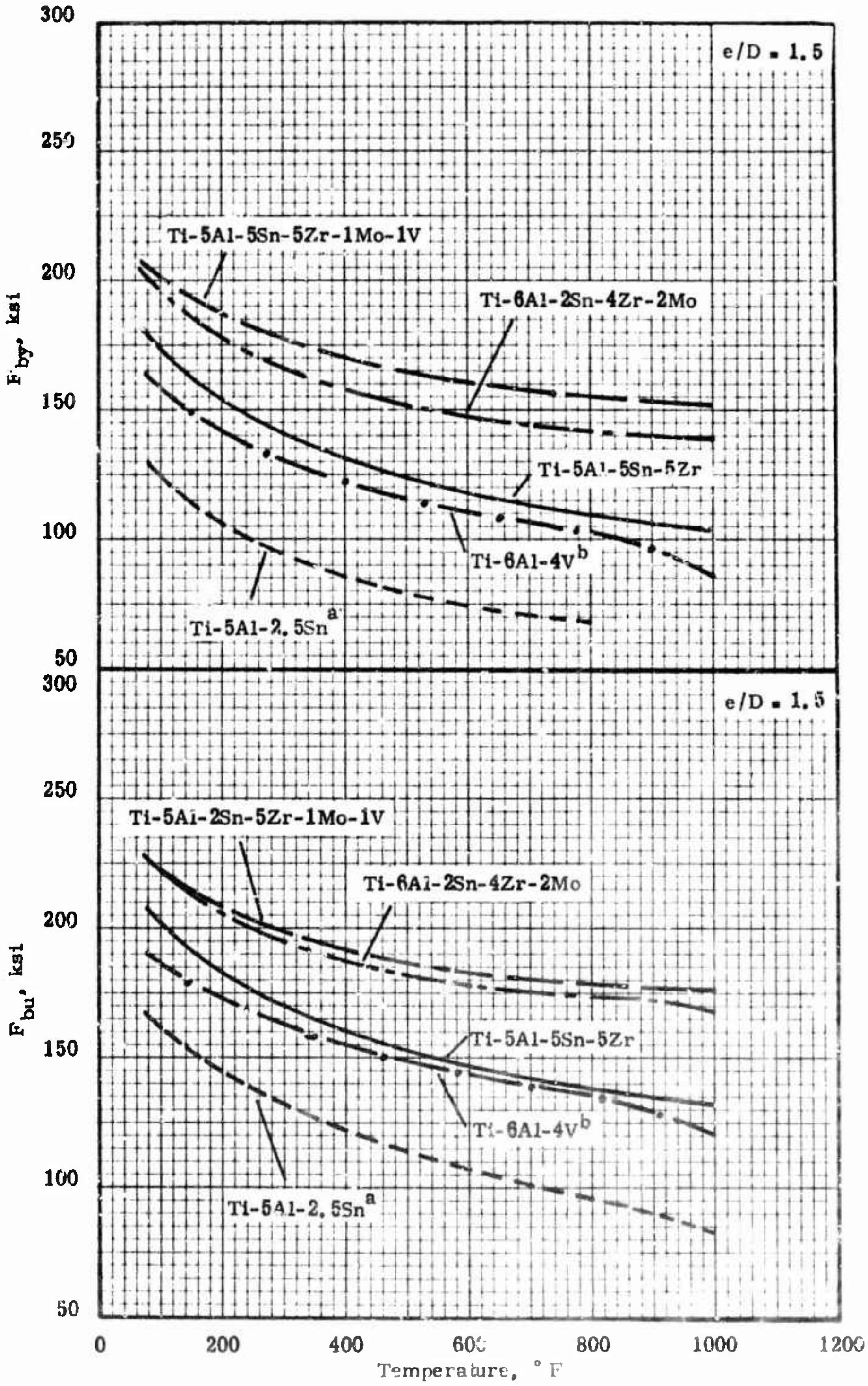


Figure 55. Comparison of the Bearing Strength (e/D = 1.5) of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for other Titanium Alloys

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Referenced data
a - MILHDBK 5, p 5.3.1.2.3 (b)
b - MILHDBK 5, p 5.4.6.2.3 (b)

Table 18

Summary of Averages and Standard Deviations for the Ultimate Shear Strength at Different Temperatures of Three Titanium Alloys in the Form of Forty-Mil Sheet.

Ti-5Al-5Sn-5Zr

Temp. °F	Longitudinal F_{su}, ksi Avg.	Longitudinal F_{su}, ksi s	Transverse F_{su}, ksi Avg.	Transverse F_{su}, ksi s
70	87.7	0.9	94.2	1.4
400	68.1	1.2	72.9	2.1
600	62.4	1.1	67.0	1.2
800	59.6	1.6	66.2	1.2
1000	56.2	1.0	62.8	0.8

Heat treatment: 1650° F, 1/2 hr, A.C.

Ti-5Al-5Sn-5Zr-1Mo-1V

Temp. °F	Longitudinal F_{su}, ksi Avg.	Longitudinal F_{su}, ksi s	Transverse F_{su}, ksi Avg.	Transverse F_{su}, ksi s
70	105.1	1.5	109.8	1.2
400	85.6	2.1	90.6	1.4
600	82.4	1.7	86.7	1.2
800	81.5	1.0	85.2	1.6
1000	72.9	1.8	77.6	0.8

Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

Ti-6Al-2Sn-4Zr-2Mo

Temp. °F	Longitudinal F_{su}, ksi Avg.	Longitudinal F_{su}, ksi s	Transverse F_{su}, ksi Avg.	Transverse F_{su}, ksi s
70	97.8	3.0	95.5	1.9
400	81.8	1.9	78.6	1.3
600	79.1	2.5	75.5	2.0
800	76.5	2.7	72.6	2.0
1000	68.9	2.0	67.2	1.5

Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

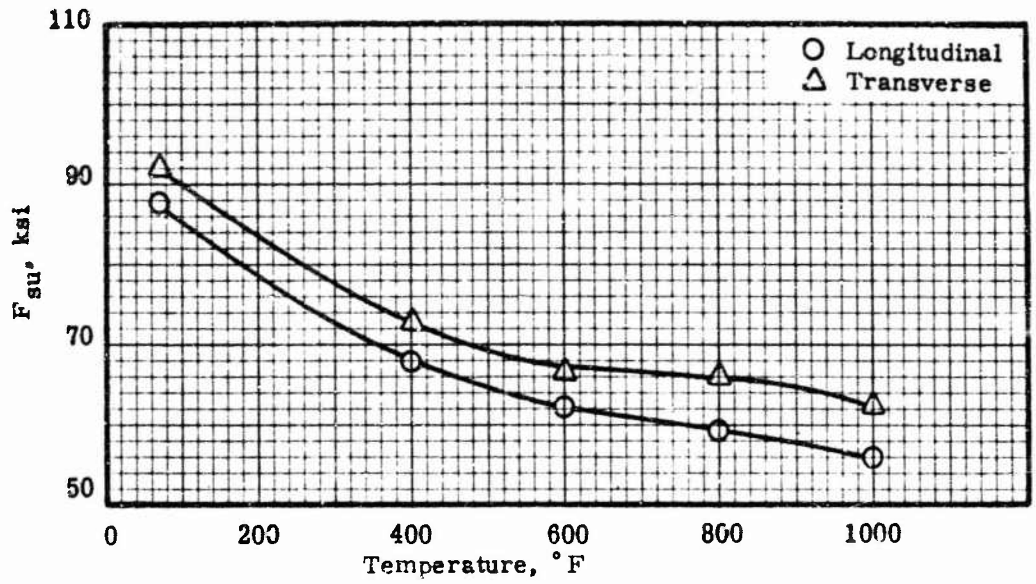


Figure 54. The Ultimate Shear Strength of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

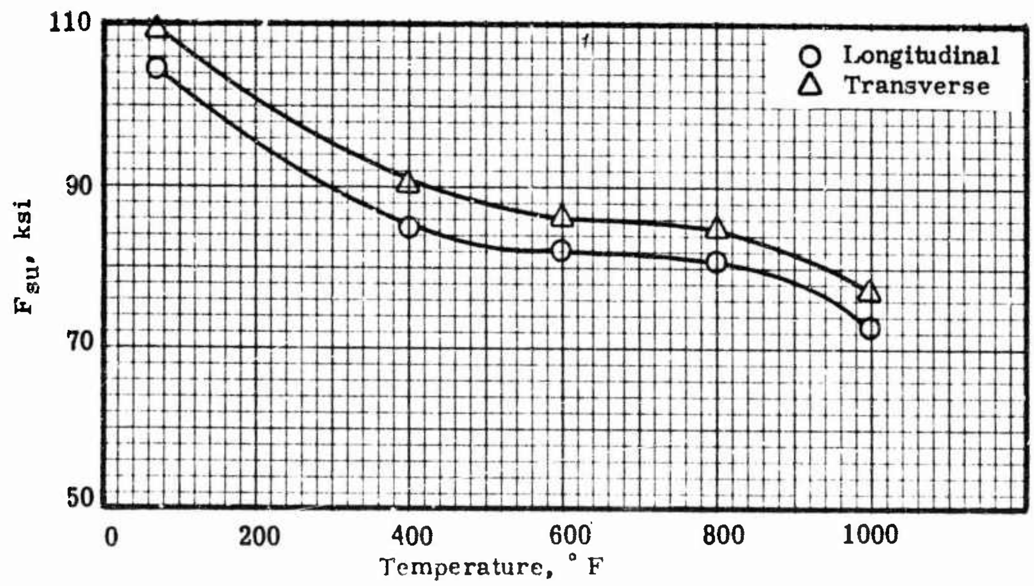


Figure 55. The Ultimate Shear Strength of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

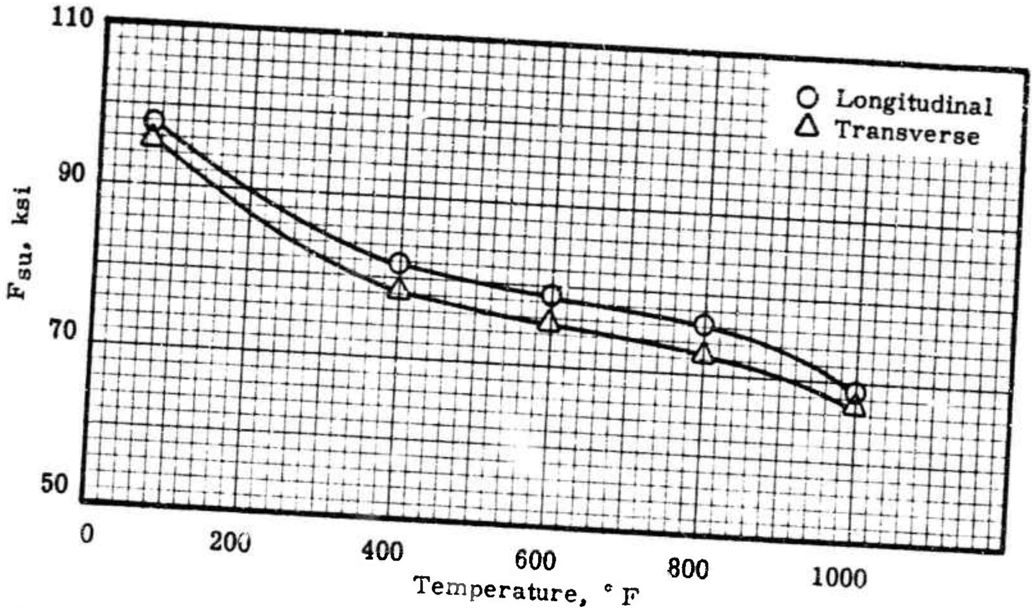
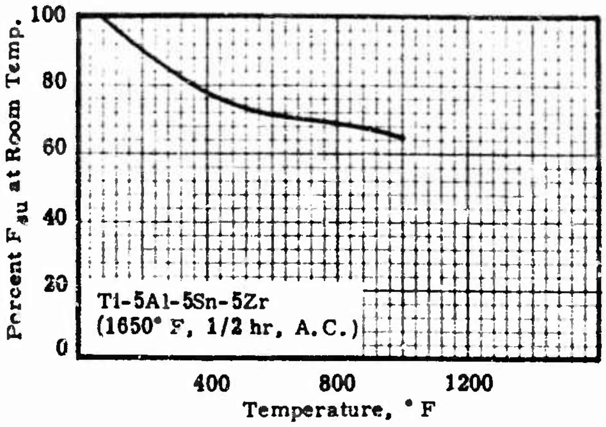
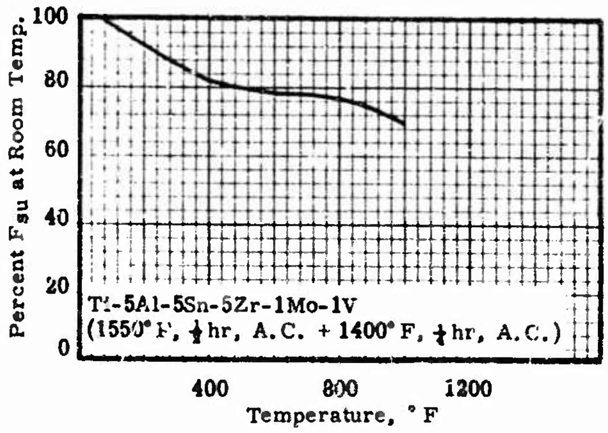


Figure 56. The Ultimate Shear Strength of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.





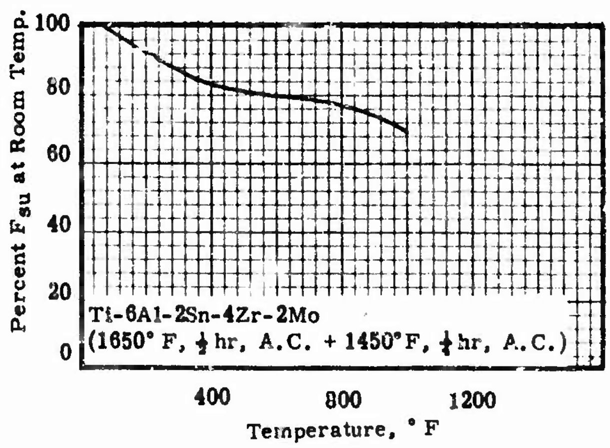


Figure 57. The Effect of Temperature on the Ultimate Shear Strength of Three Titanium Alloys.

Sheet thickness: 40 mils
Heat treatment: As shown for each alloy.

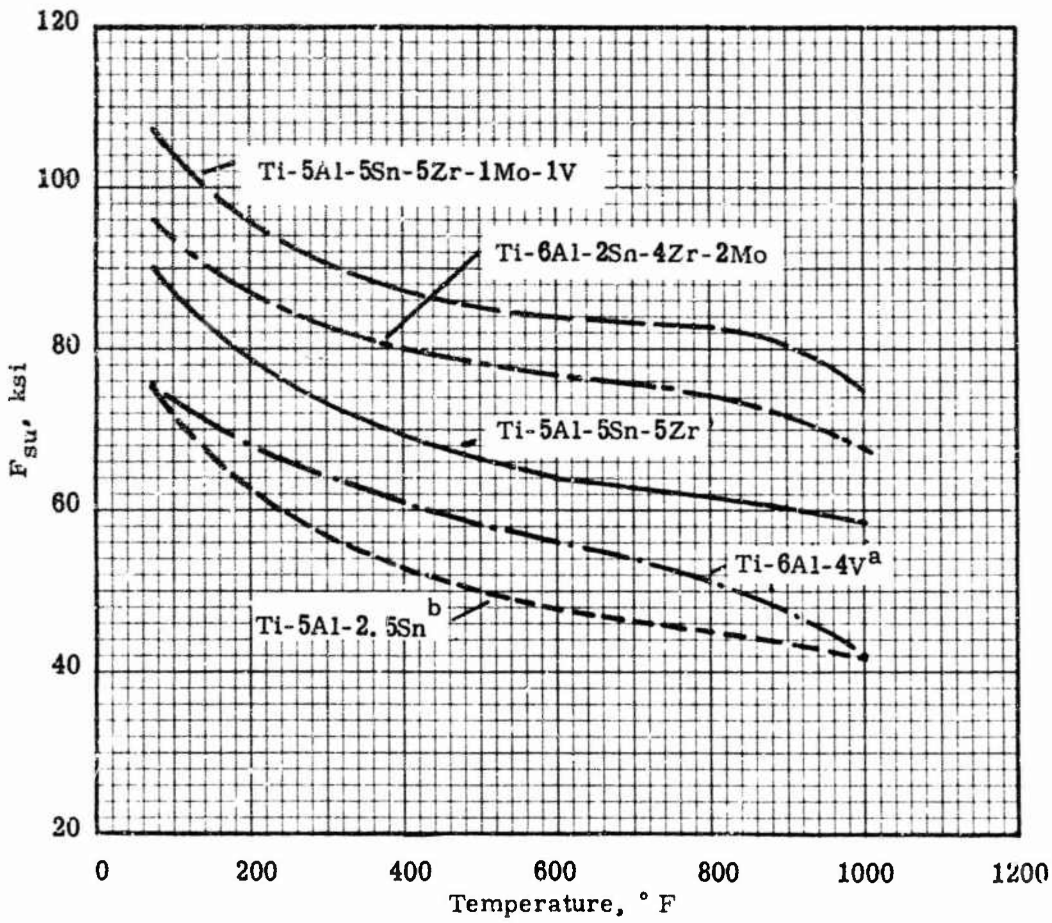


Figure 58. Comparison of Ultimate Shear Strength of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data

a MIL HDBK 5, p 5.4.6.2.3 (b)
b MIL HDBK 5, p 5.3.1.2.2 (a)

The shear strength of the Ti-5Al-5Sn-5Zr and Ti-5Al-5Sn-5Zr-1Mo-1V alloys was slightly higher in the transverse direction than in the longitudinal direction, and approximately equal for both directions of the Ti-6Al-2Sn-4Zr-2Mo sheet. The shear strength for all the sheet alloys was 0.65 to 0.70 of the respective tensile strength at comparable temperatures, which is normal for most materials. The comparative data plotted in Figure 58 shows that the shear strength of the Ti-5Al-5Sn-5Zr-1Mo-1V alloy is higher at all test temperatures than the other alpha-beta alloy (Ti-6Al-2Sn-4Zr-2Mo) evaluated in the program as well as the comparative alloy, Ti-6Al-4V. The shear strength of the Ti-5Al-5Sn-5Zr sheet was greater than the comparative all-alpha alloy (Ti-5Al-2.5Sn) and the Ti-6Al-4V alloy at all test temperatures.

Thermal-Exposure

The results of mechanical-property tests on longitudinally oriented specimens of the sheet alloys after thermal exposure from 600 to 1200° F for times from 10 to 1000 hr are given in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	59, 62	52, 53, 58
Ti-5Al-5Sn-5Zr-1Mo-1V	60, 63	<u>54</u>, <u>55</u>, <u>58</u>
Ti-6Al-2Sn-4Zr-2Mo	61, 64	<u>56</u>, <u>57</u>, <u>58</u>

Tables with numbers underlined are in Appendix I

Figures 59 - 61 and 62 - 64 show the tensile and shear strength properties of the sheet alloys after thermal exposure. The top graph of each figure shows the strength property at room temperature as a function of the exposure temperature; the bottom graph of each figure shows the property at the exposure temperature as a function of the exposure temperature. Thermal exposure had no deleterious effect on the strength of the alloys. The curves of shear strength and tensile strength at room temperature as functions of exposure temperature show a promounced increase in strength of the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alpha-beta alloys after exposure to 600, 800, and 1000° F; however this increase in strength is probably due to aging. Above 800° F over-aging occurred in long-time exposure, which caused a decrease in the strength properties.

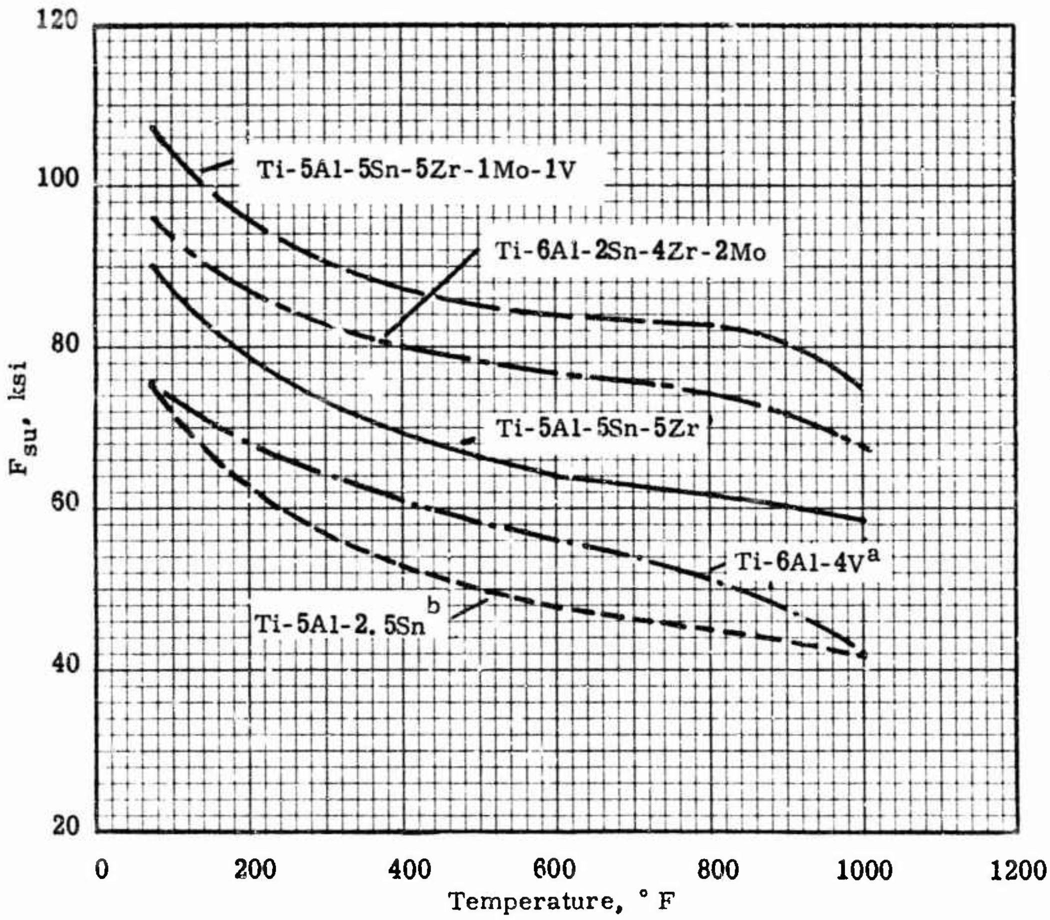
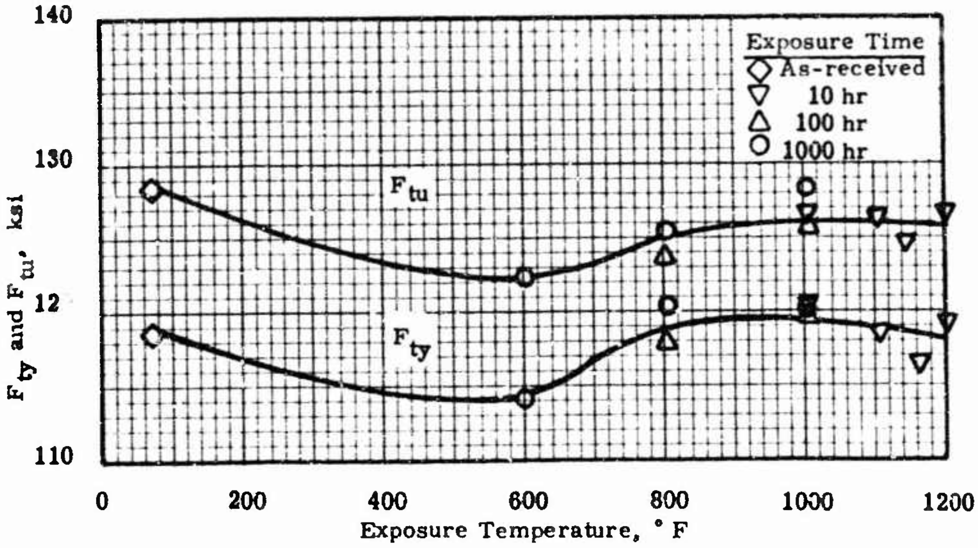


Figure 58. Comparison of Ultimate Shear Strength of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data

a MIL HDBK 5, p 5.4.6.2.3 (b)
b MIL HDBK 5, p 5.3.1.2.2 (a)



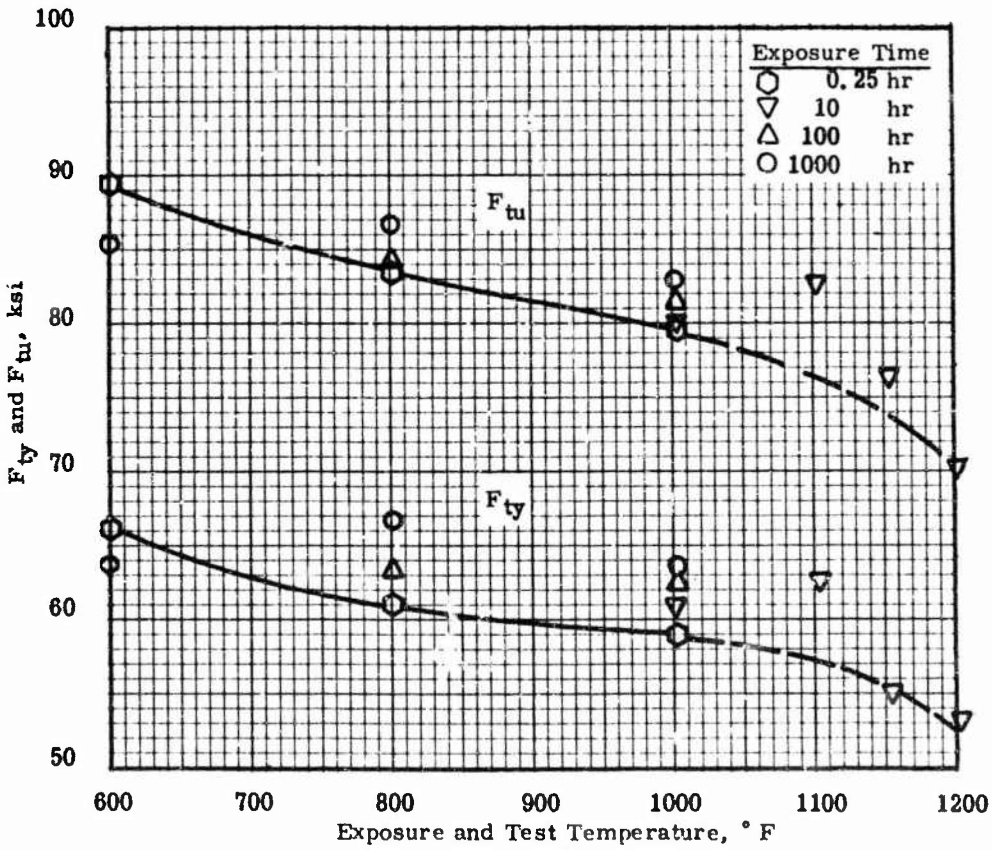
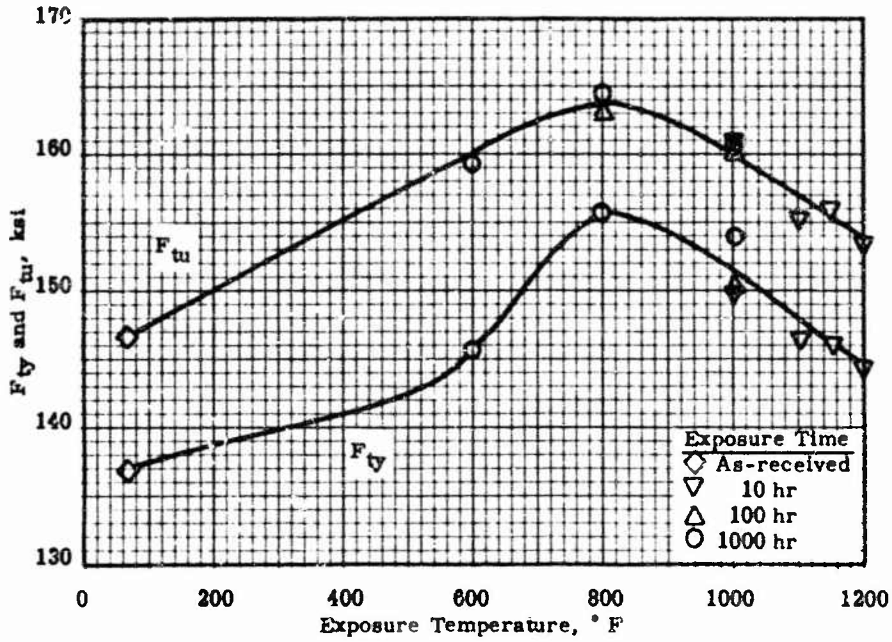


Figure 59. Effect of Thermal Exposure on the Tensile-Strength Properties of Ti-5Al-5Sn-5Zr Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.



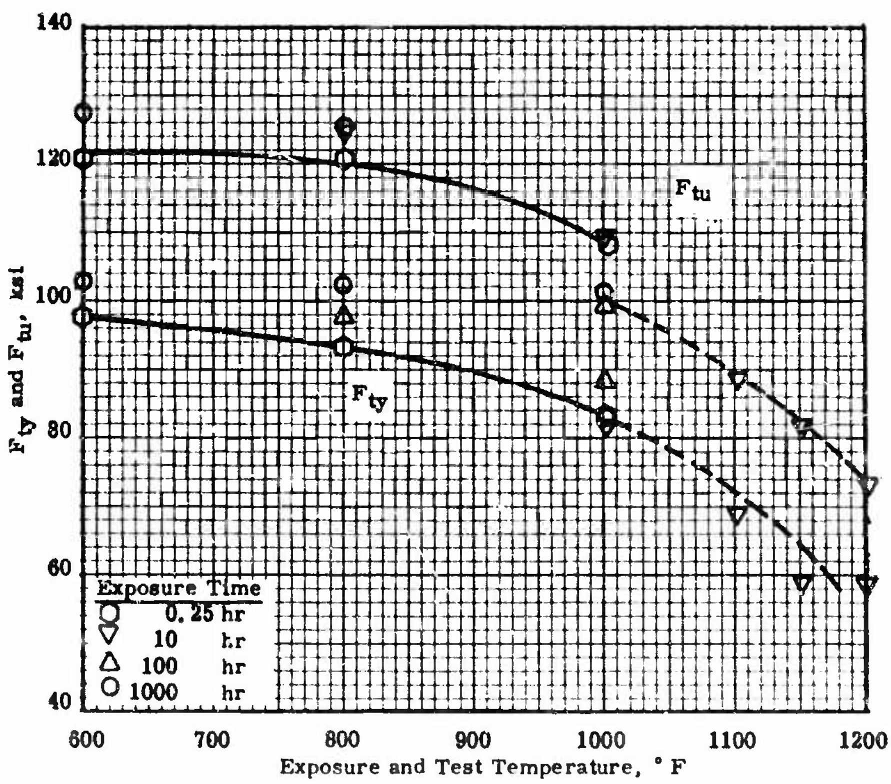


Figure 60. Effect of Thermal Exposure on the Tensile-Strength Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. V-2957
Thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

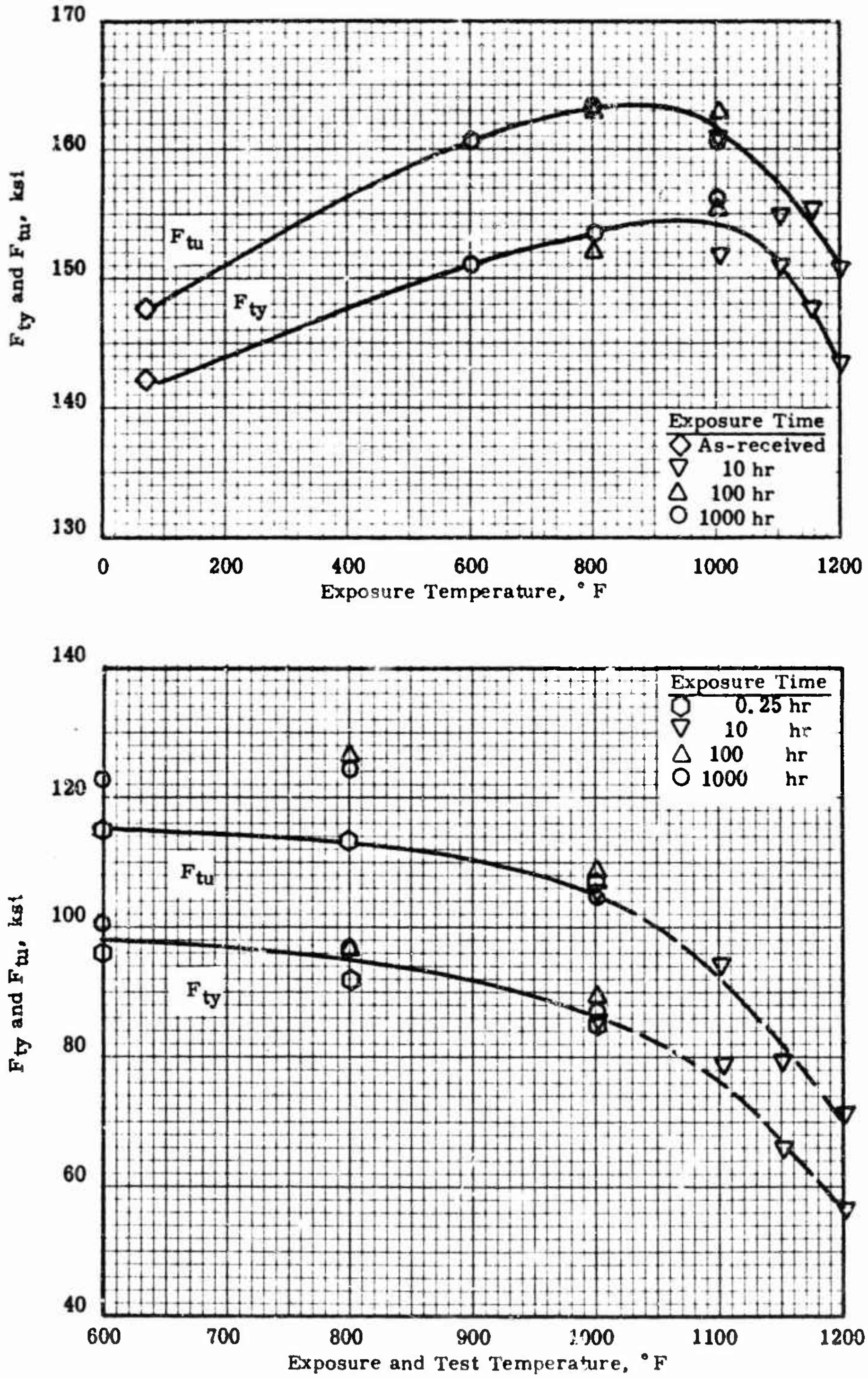
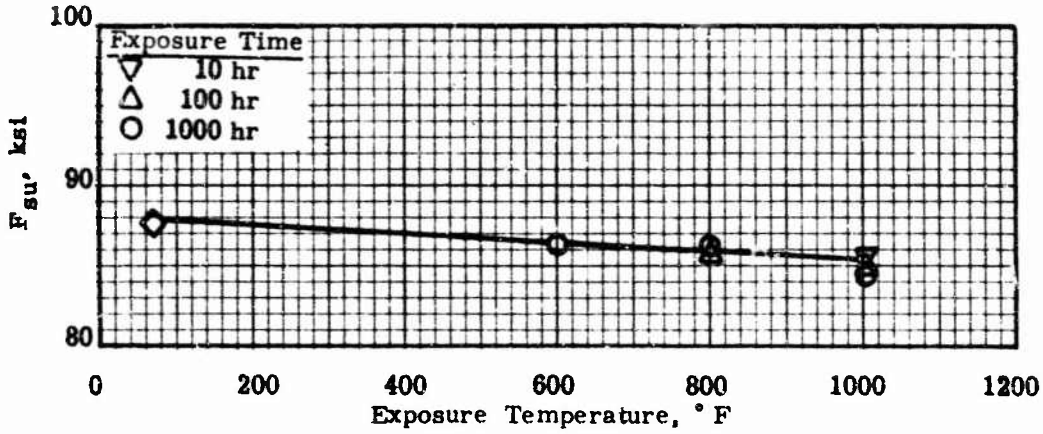


Figure 61. Effect of Thermal Exposure on the Tensile-Strength Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



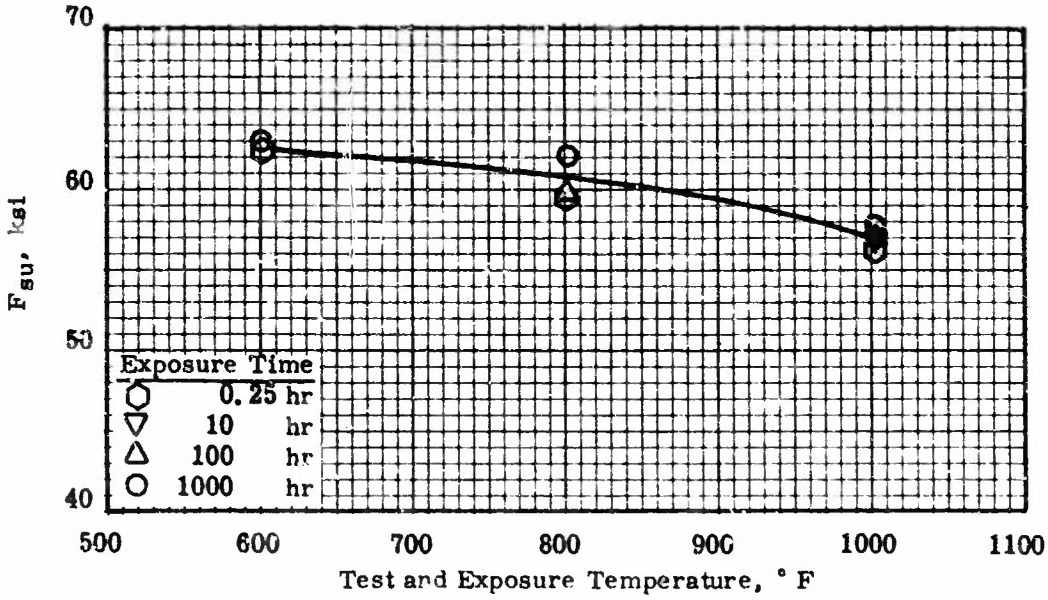


Figure 62. The Effect of Thermal Exposure on the Ultimate Shear Strength of Ti-5Al-5Sn-5Zr Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/4 hr, A.C.

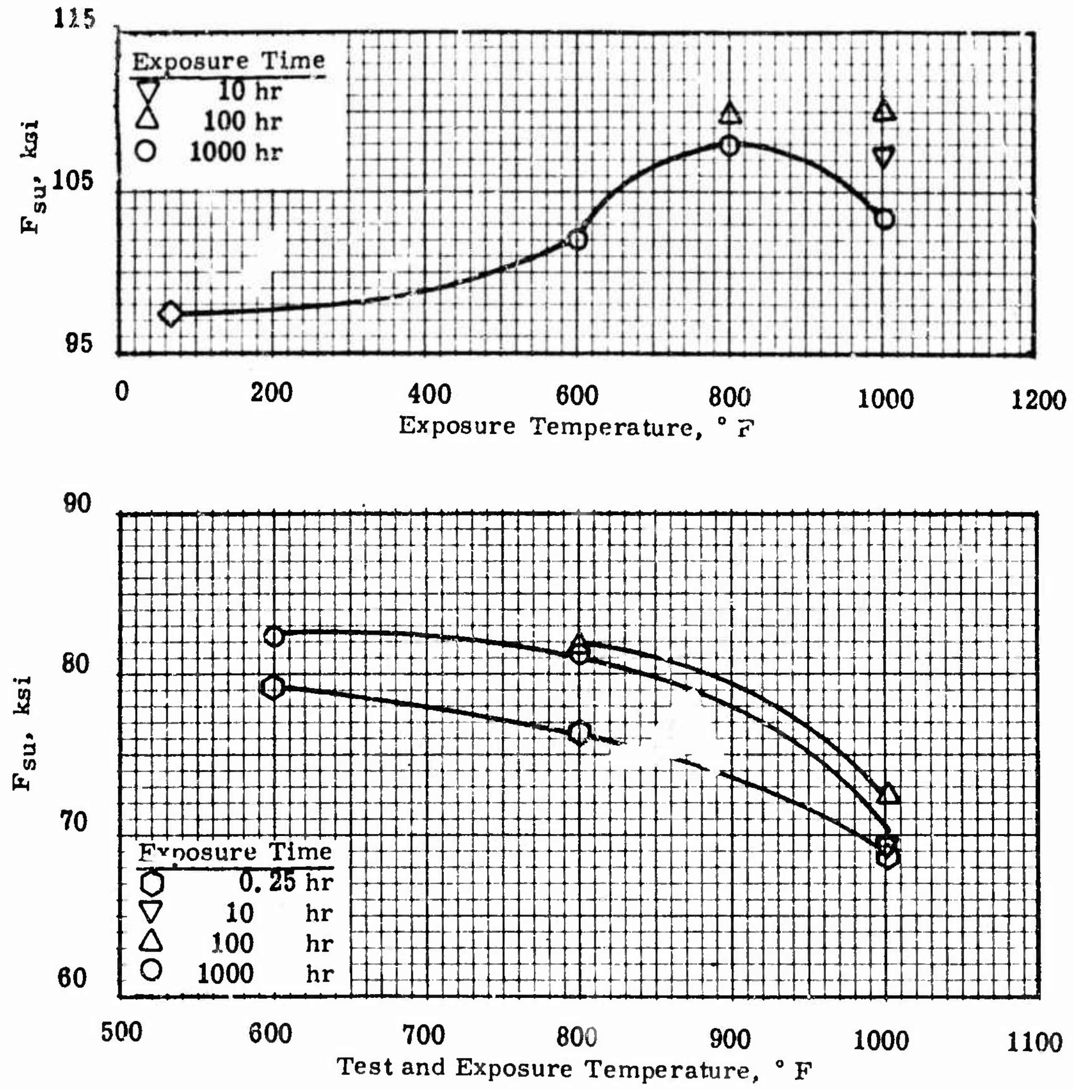


Figure 64. The Effect of Thermal Exposure on the Ultimate Shear Strength of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

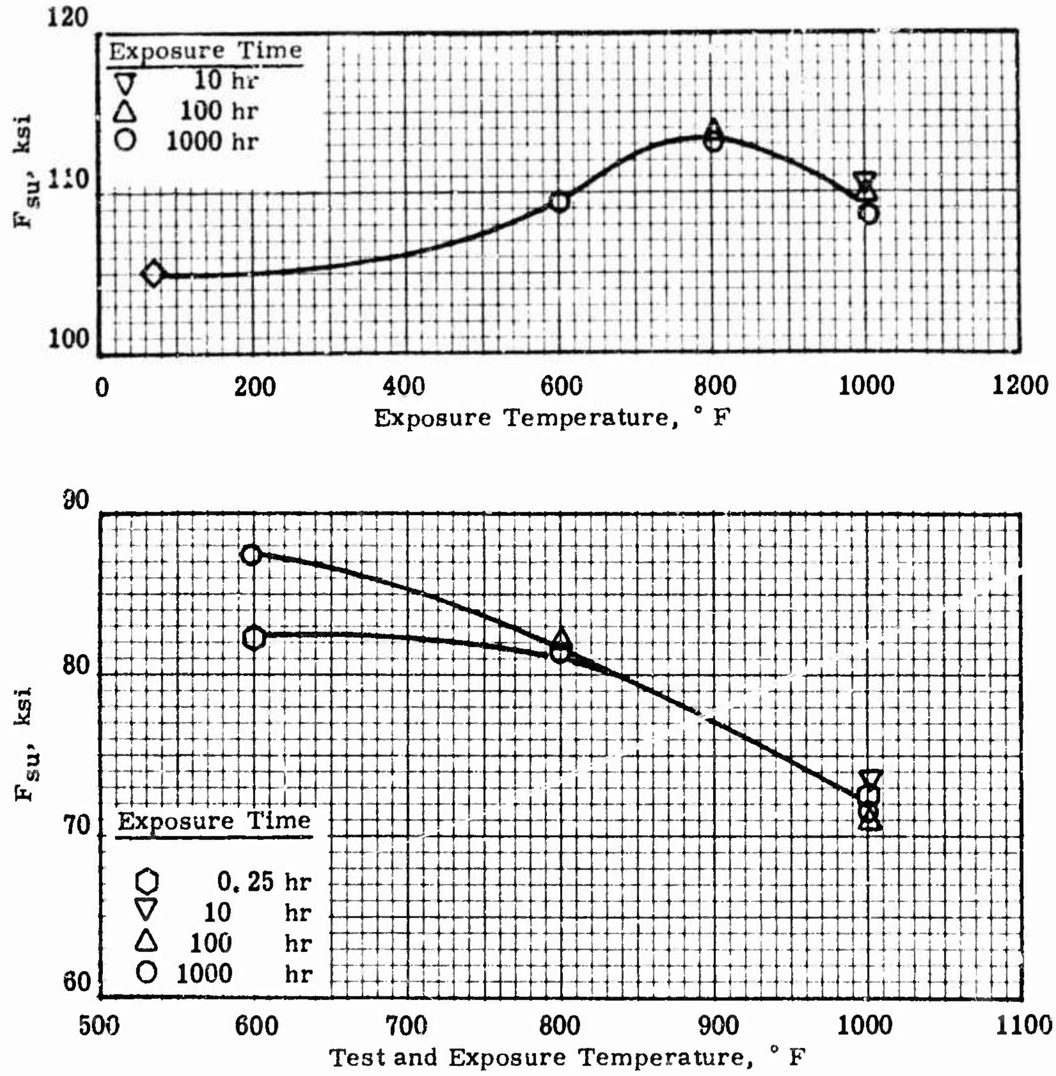


Figure 63. The Effect of Thermal Exposure on the Ultimate Shear Strength of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

Creep

Creep strain data for the longitudinal orientation of the sheet alloys are shown in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	65, 66, 67, 68, 78, 79	59
Ti-5Al-5Sn-5Zr-1Mo-1V	69, 70, 71, 72, 73, 78, 79	<u>60</u>
Ti-6Al-2Sn-4Zr-2Mo	74, 75, 76, 77, 78, 79	<u>61</u>

Tables with numbers underlined are in Appendix I.

The comparative creep strength of the three sheet alloys evaluated in this program with two other titanium alloys for which data were available is shown in Figures 78 and 79. The basis for comparison is the stress for 0.1% creep strain (Figure 78) and 0.5% creep strain (Figure 79) as a function of the Larson-Miller time-temperature parameter. As these figures show, the Ti-5Al-5Sn-5Zr alloy has higher creep strength than the alpha-beta alloys, particularly at higher temperatures. The Ti-6Al-2Sn-4Zr-2Mo alloy had higher creep strength than the Ti-5Al-5Sn-5Zr-1Mo-1V alloy. Both the alpha-beta alloys and the all-alpha alloy evaluated in this program exhibited higher creep strength than the respective comparative alpha-beta (Ti-6Al-4V) and the all-alpha (Ti-5Al-2.5Sn) alloys.

Fatigue

Data on the fatigue properties of the three sheet alloys in the longitudinal orientation may be found in the following figures and tables:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	80, 81, 82, 83, 84	62
Ti-5Al-5Sn-5Zr-1Mo-1V	85, 86, 87, 88, 89	<u>63</u>
Ti-6Al-2Sn-4Zr-2Mo	90, 91, 92, 93, 94	<u>64</u>

Tables with numbers underlined are in Appendix I.

The effect of temperature on the fatigue strength at 10^7 cycles was not as great as might be expected from the tensile properties of the alloys. In some instances the maximum-stress for 10^7 cycle endurance was greater at 400° F than at 70° F. In general, the order of decreasing fatigue strength of the sheet alloys in the unnotched condition was (a) Ti-6Al-2Sn-4Zr-2Mo, (b) Ti-5Al-5Sn-5Zr-1Mo-1V, and (c) Ti-5Al-5Sn-5Zr.

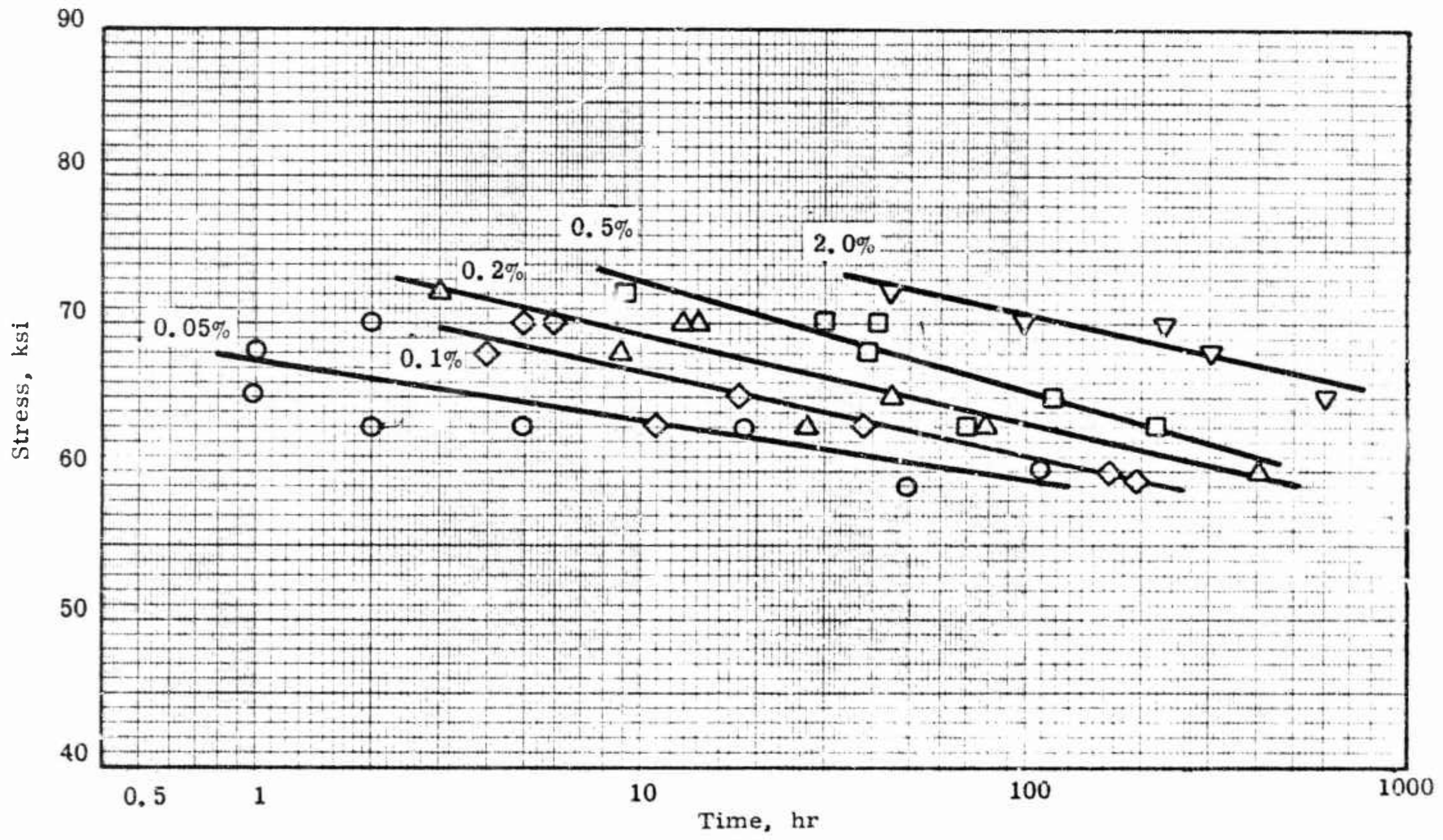


Figure 65. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Sheet at 900° F.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

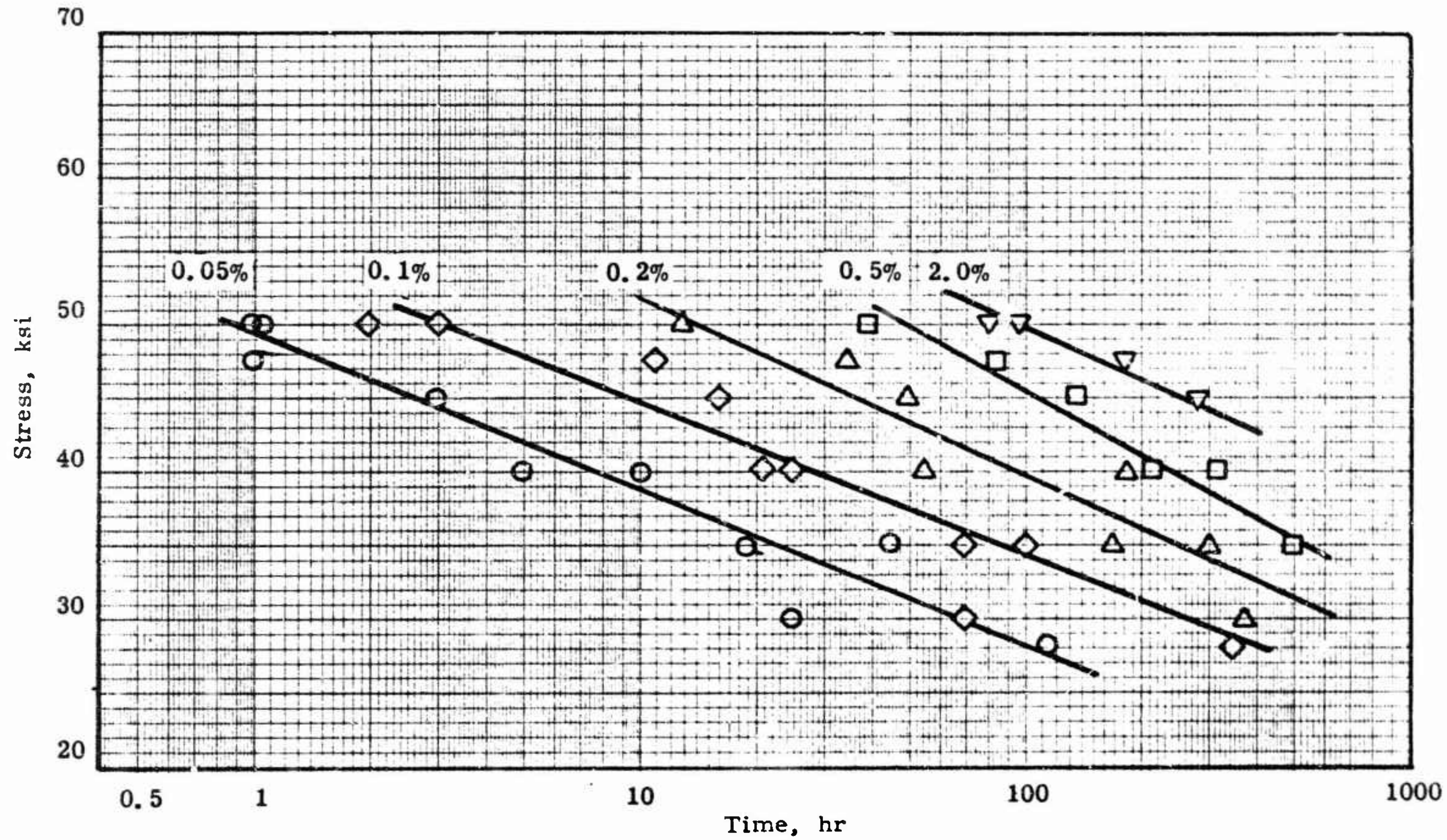


Figure 66. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Sheet at 1000° F.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

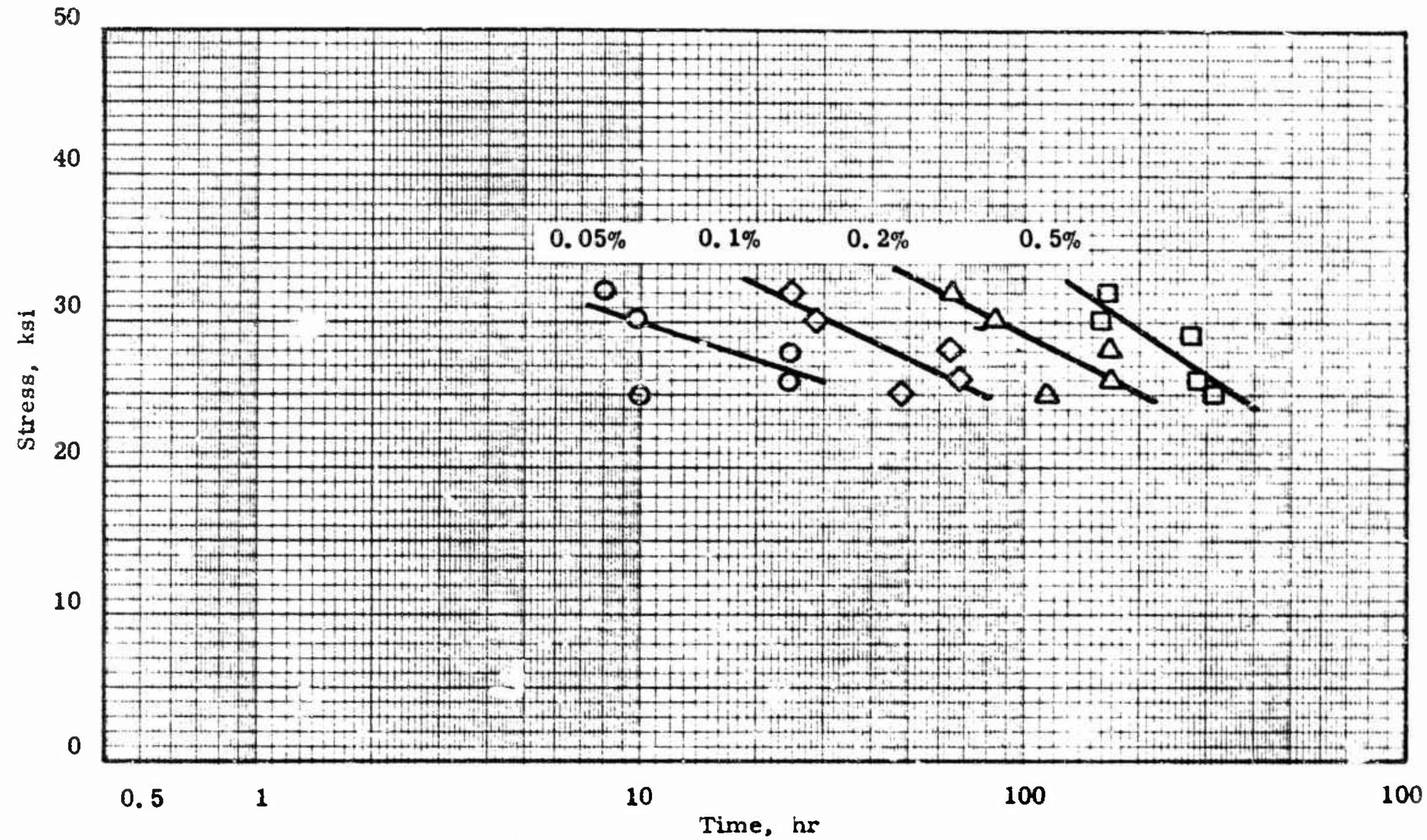


Figure 67. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Sheet at 1050° F.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

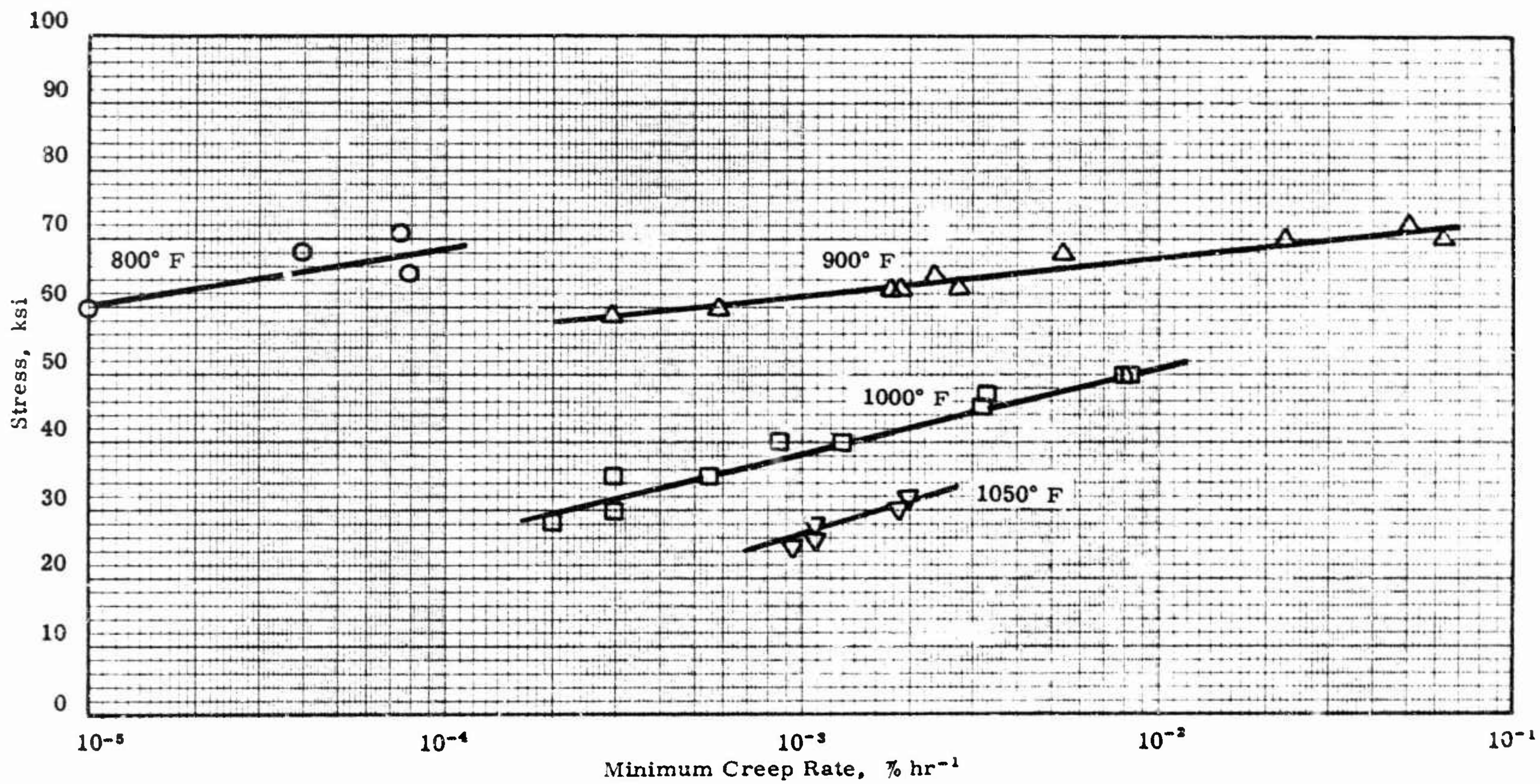


Figure 68. Minimum Creep Rate of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

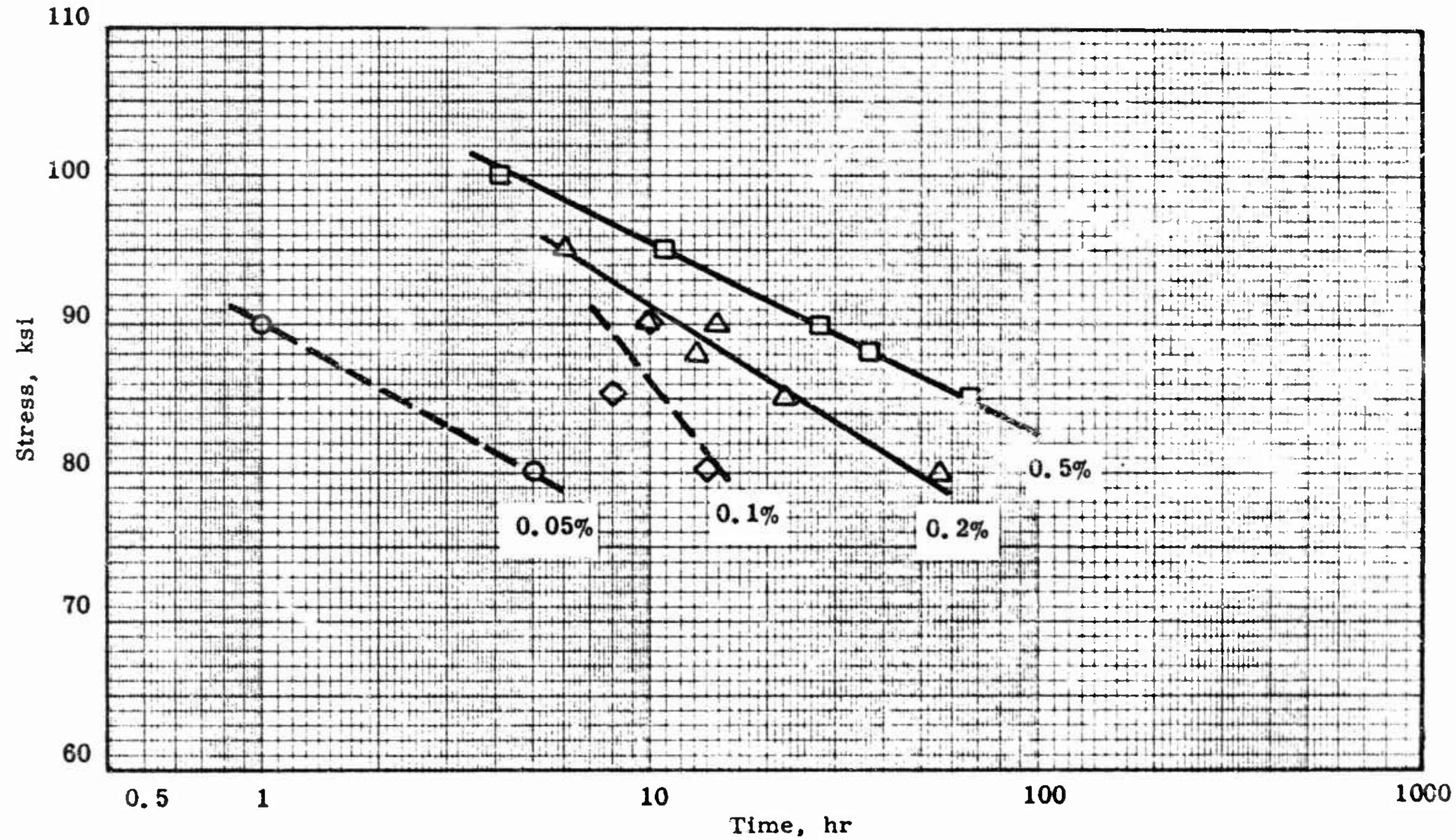


Figure 69. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 600° F.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

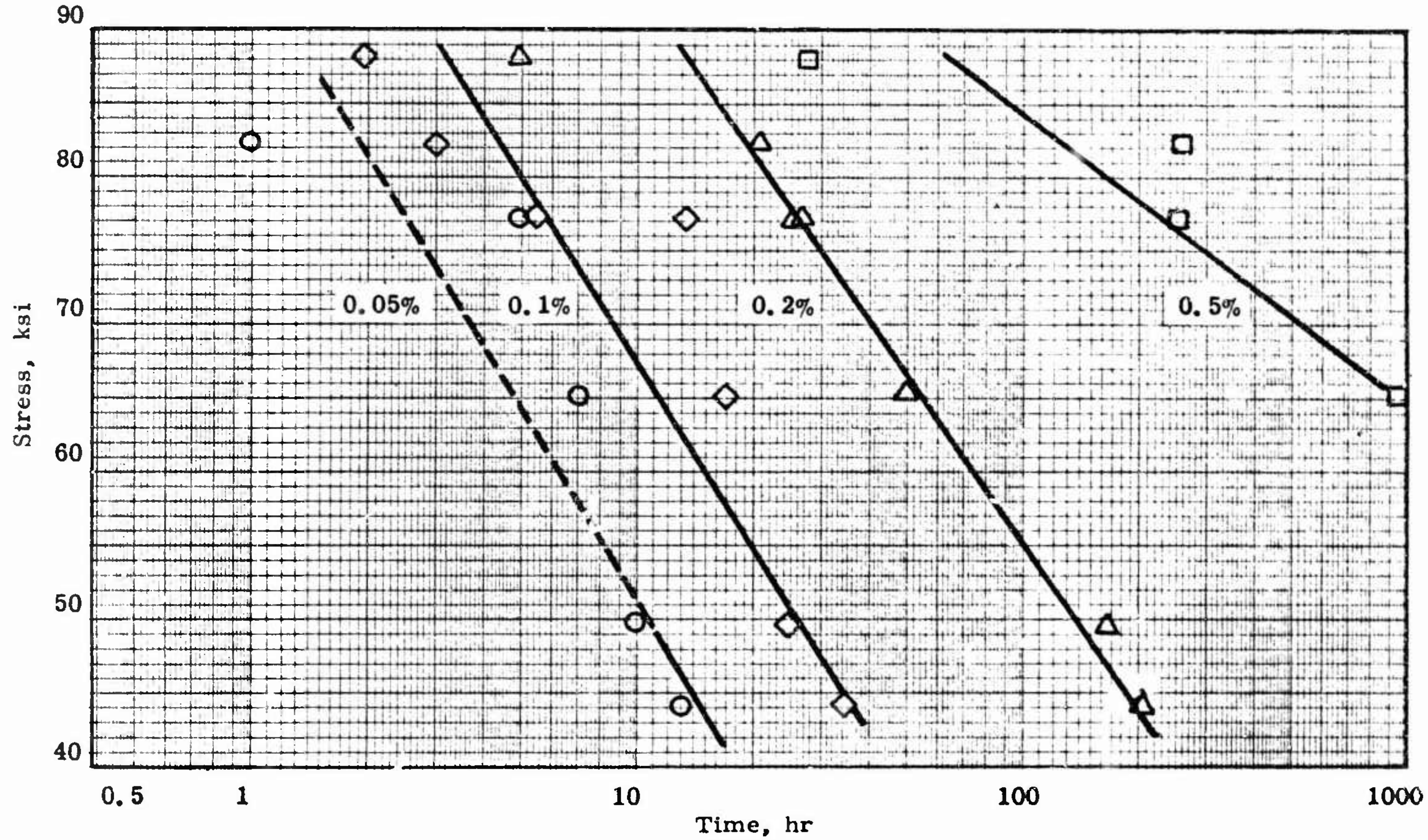


Figure 70. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 800° F.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

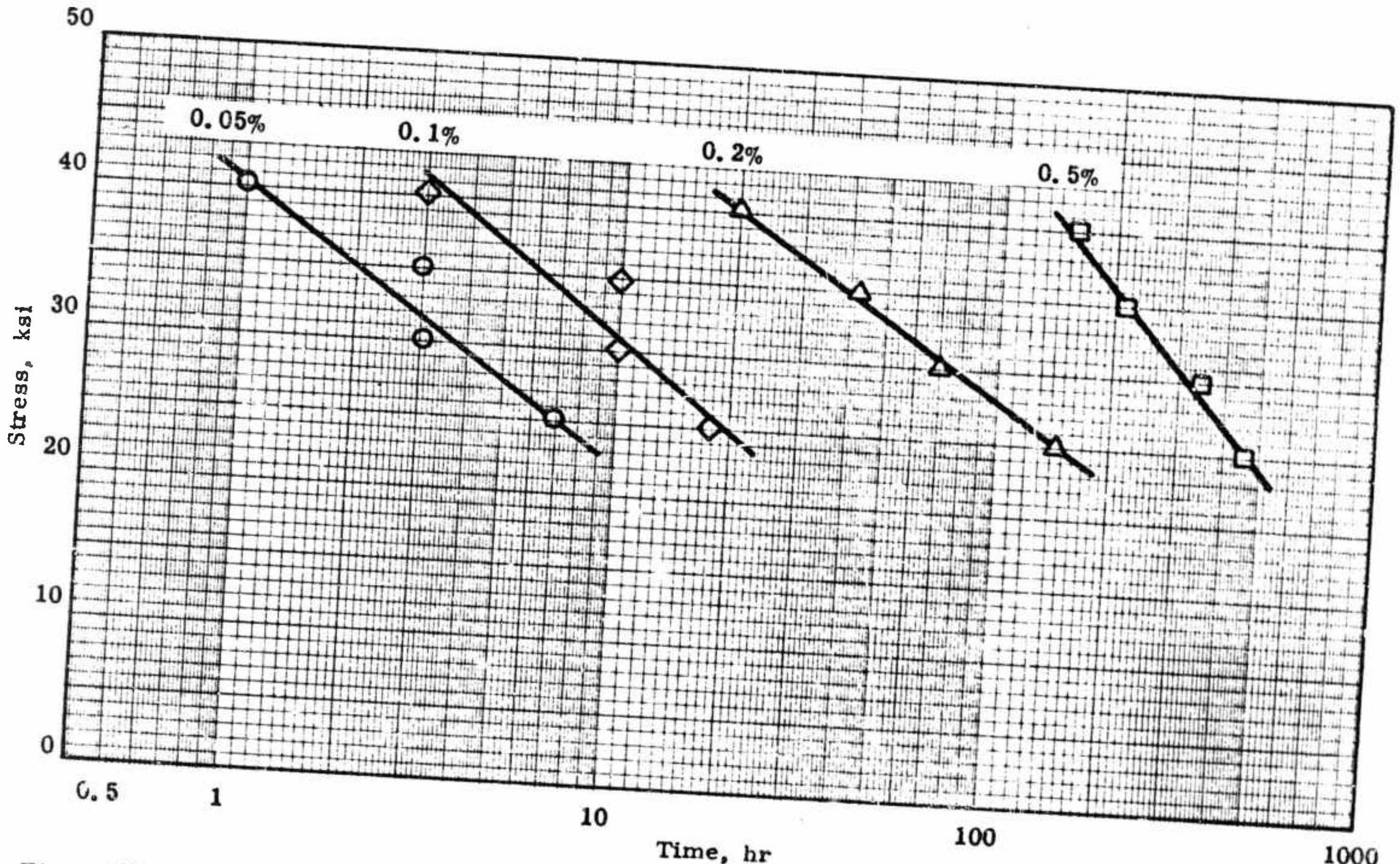


Figure 71. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 900° F.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

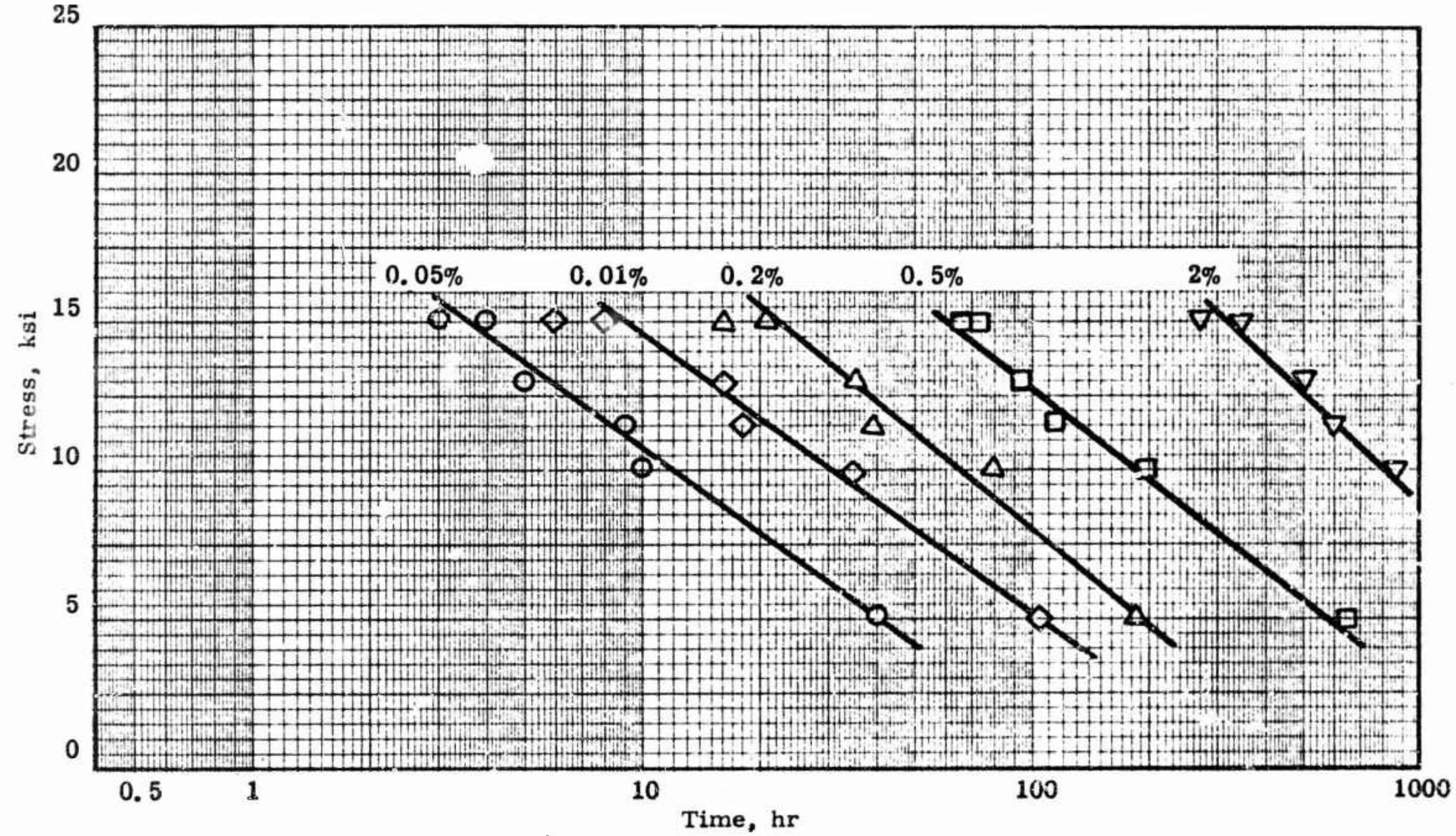


Figure 72. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 1000° F.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

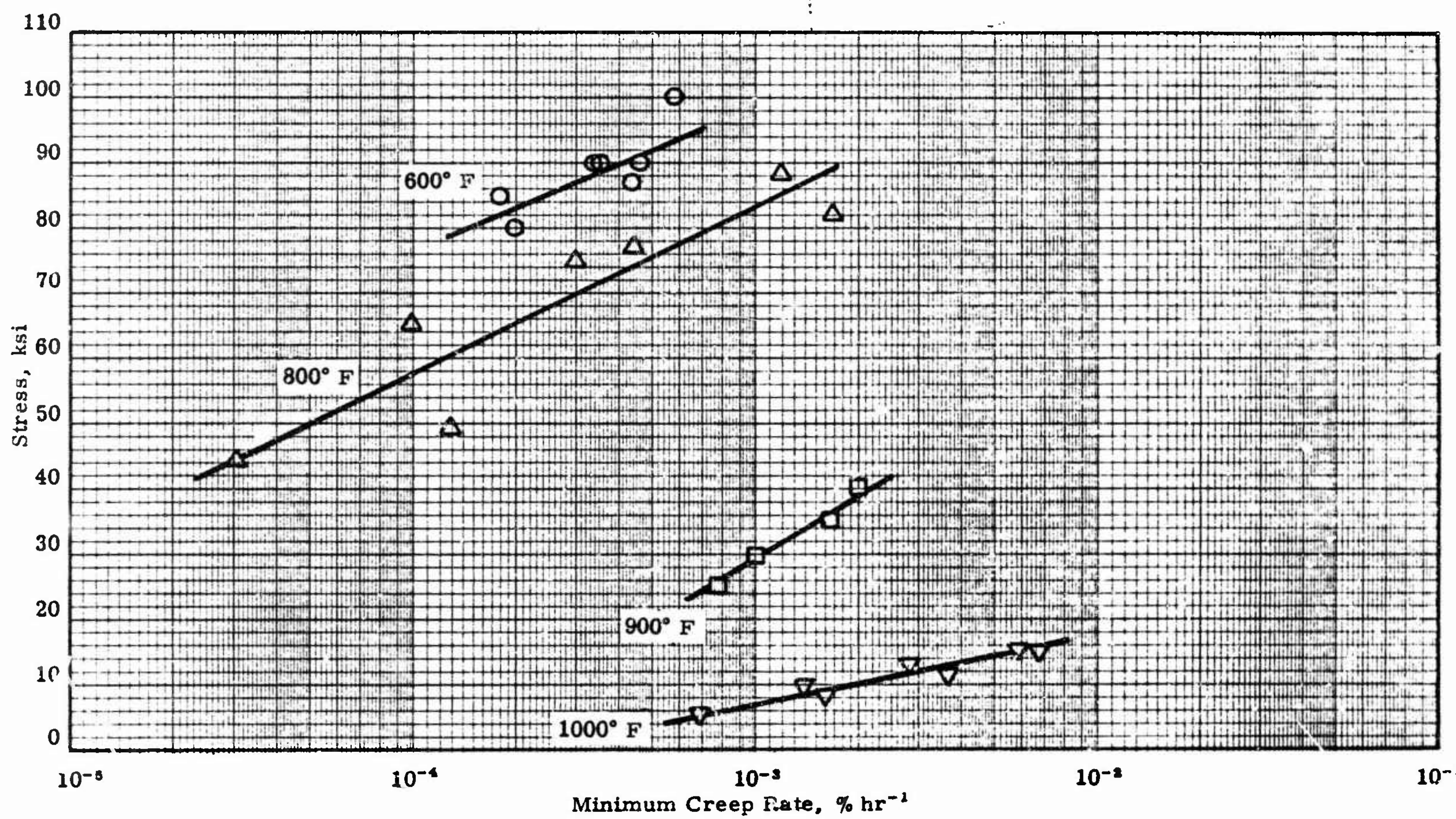


Figure 73. Minimum Creep Rate of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

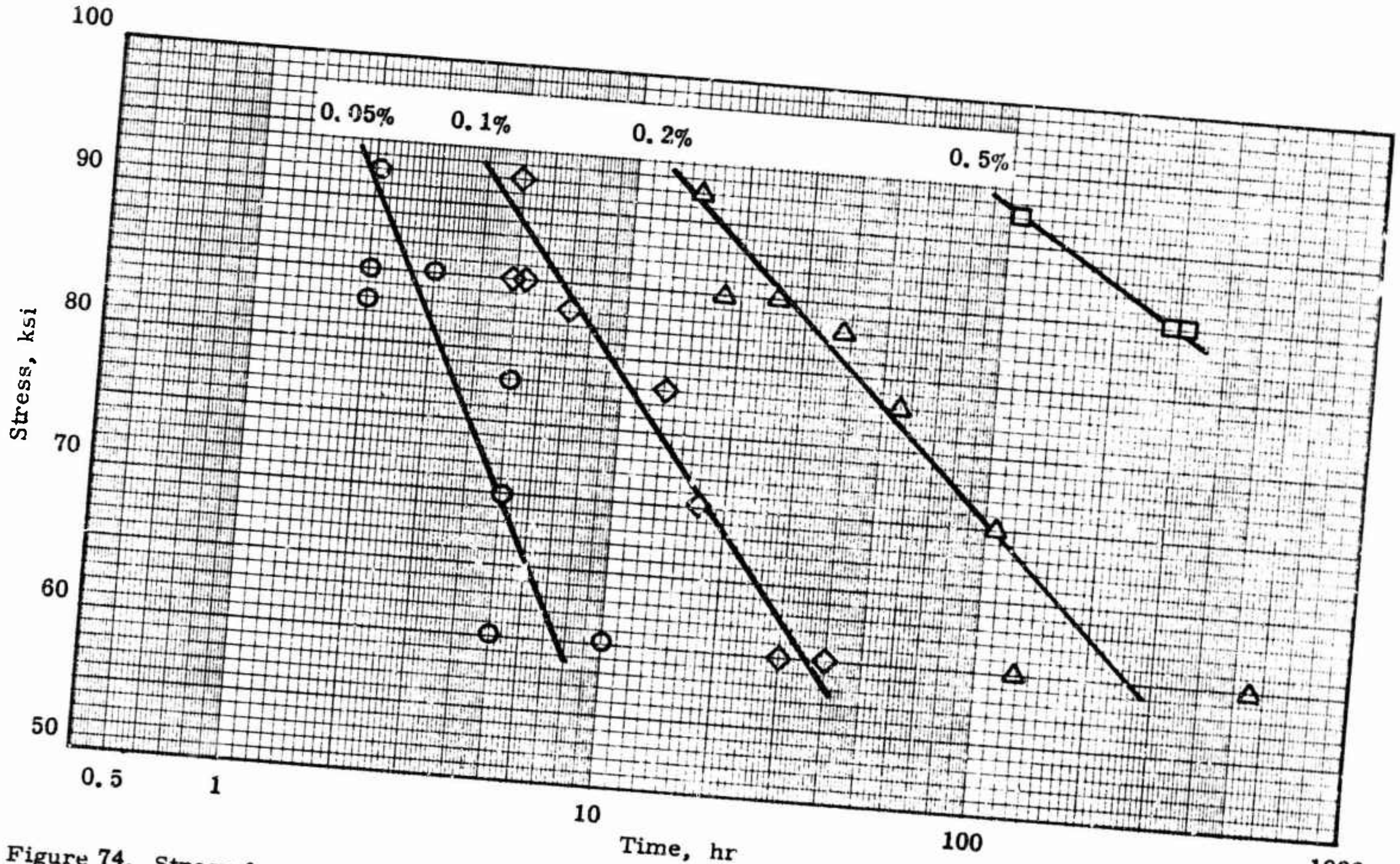


Figure 74. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 800° F.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

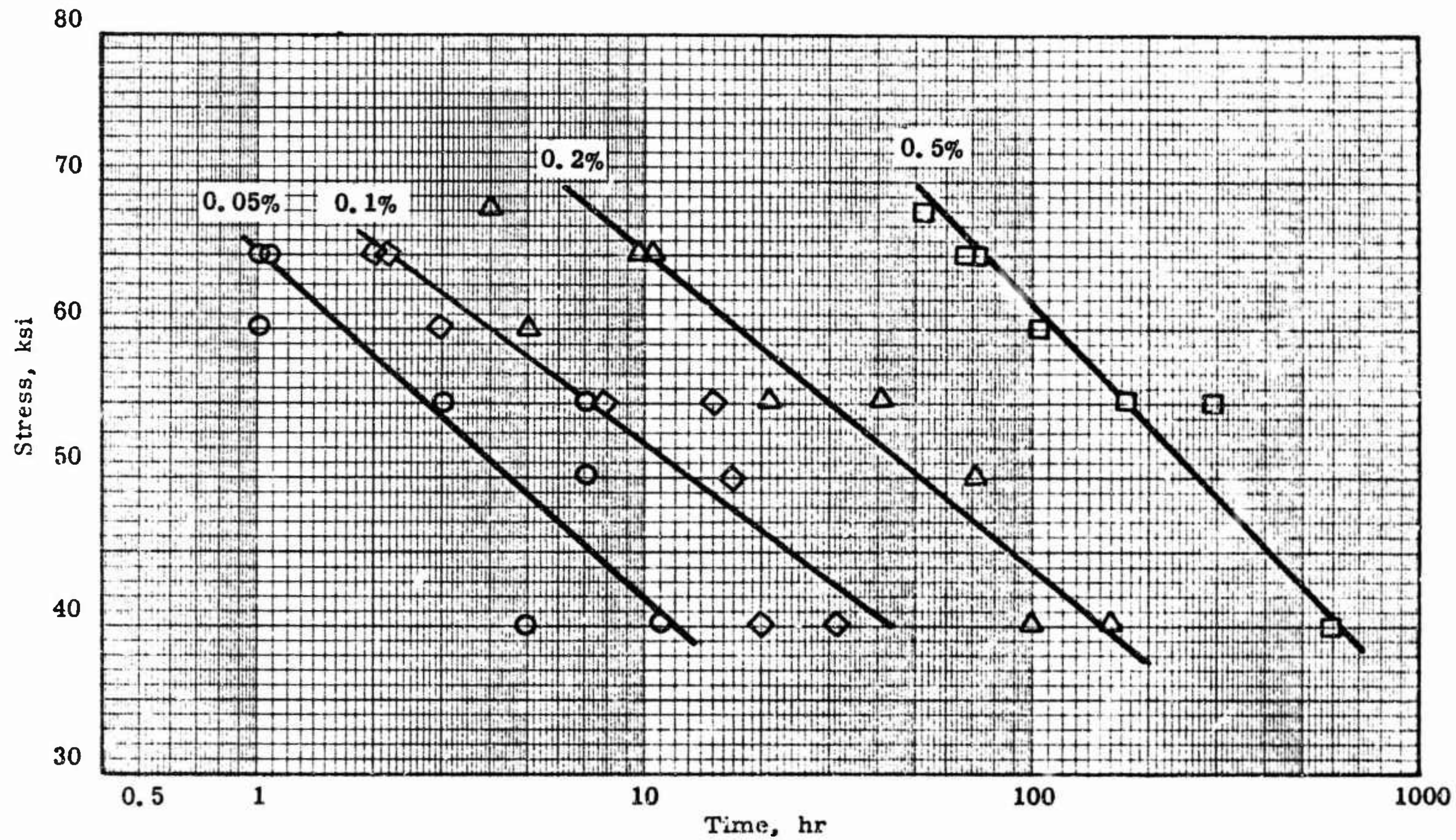


Figure 75. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 900° F.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

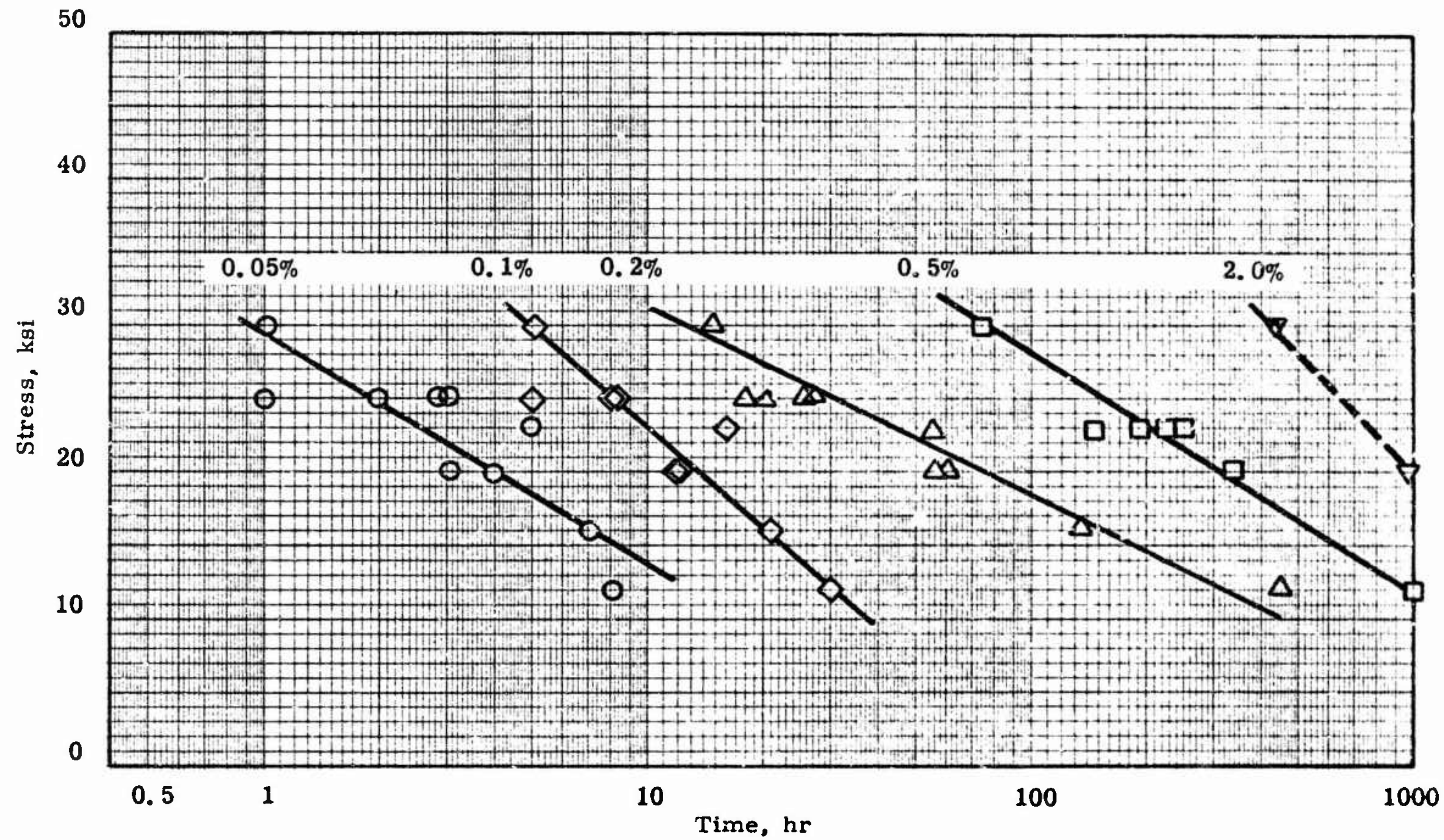


Figure 76. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 1000° F.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

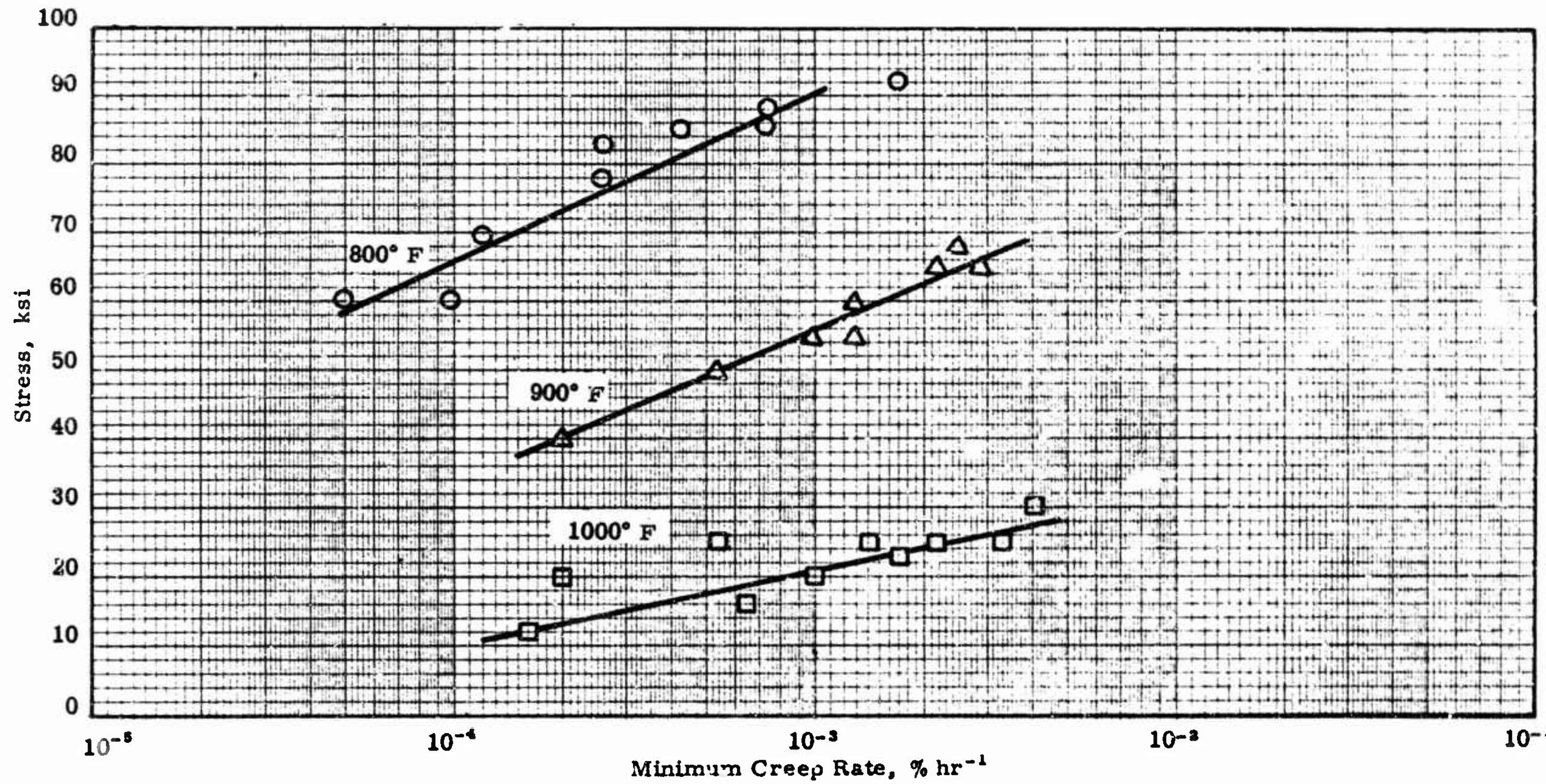


Figure 77. Minimum Creep Rate of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

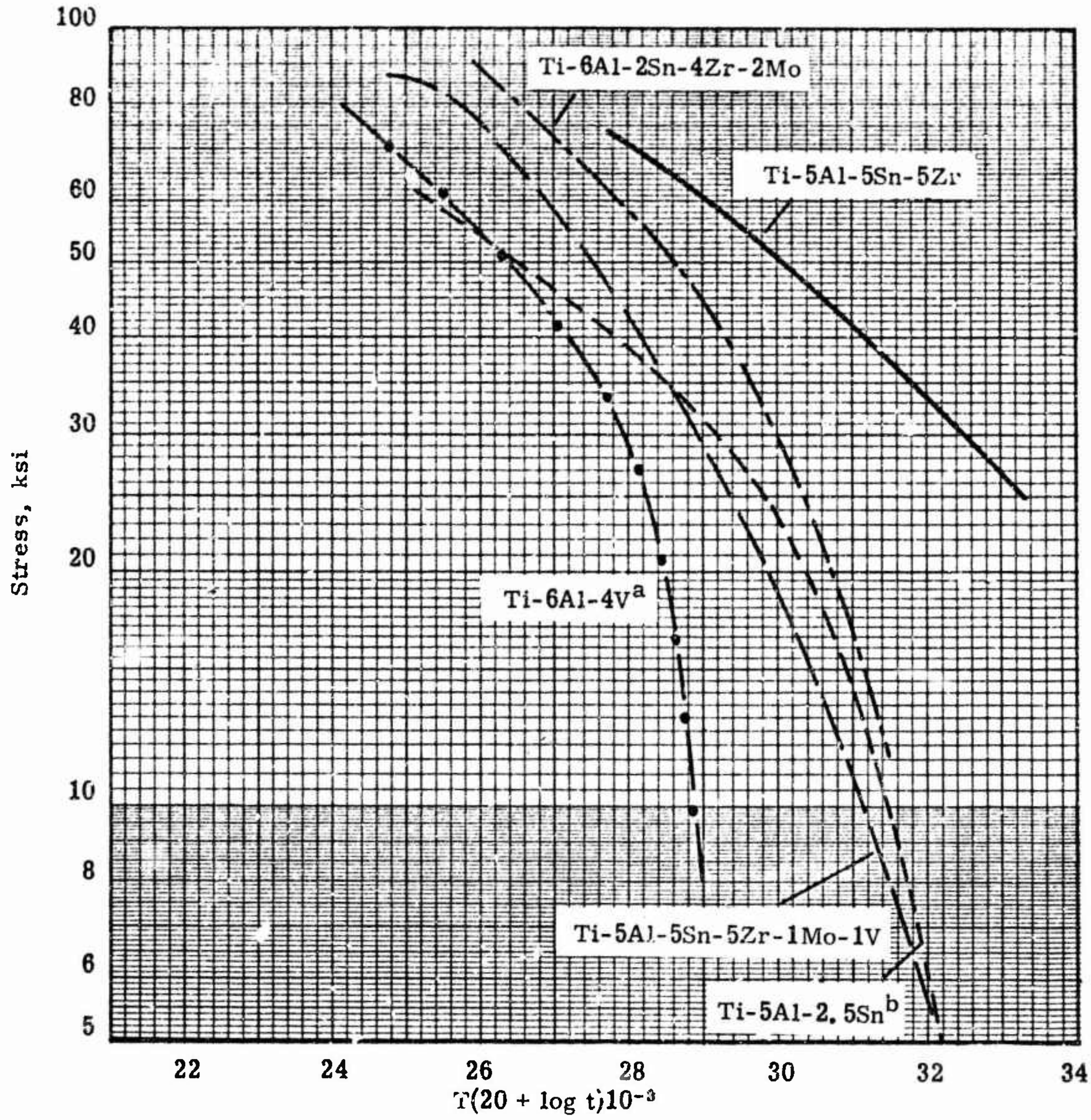


Figure 78. Comparison of Creep Strength at 0.1% Creep Deformation of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data
a - Aerospace Hdbk, Vol II, Code 3701, p 13
Properties of Ti-6Al-4V, TMCA
b - Aerospace Hdbk, Vol II, Code 3706, p 7

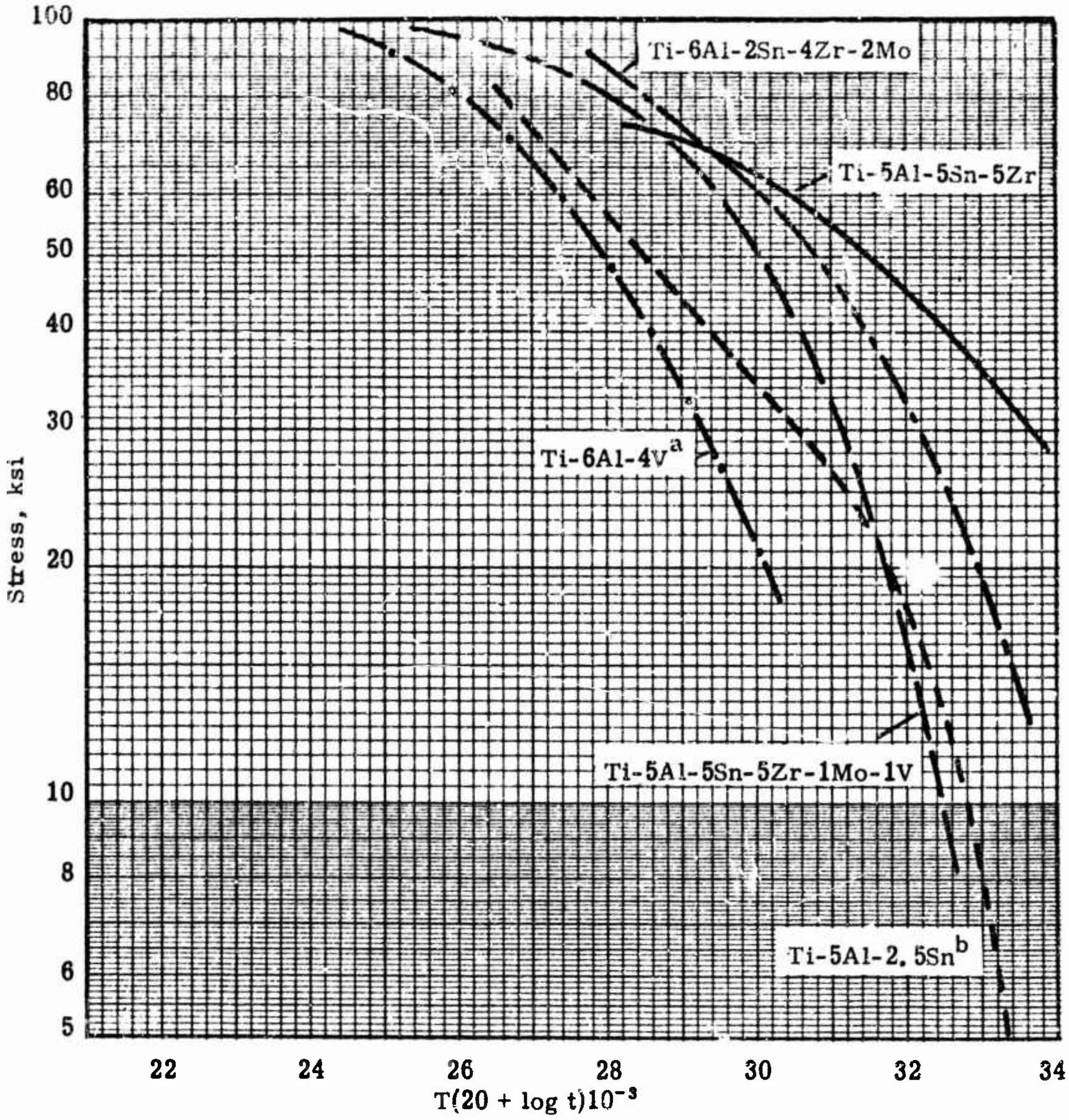


Figure 79. Comparison of Creep Strength at 0.5% Creep Deformation of Titanium Sheet Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data

a - Aerospace Hdbk, Vol II, Code 3707, p 13
Properties of Ti-6Al-4V, TMCA

b - Aerospace Hdbk, Vol II, Code 3706, p 7

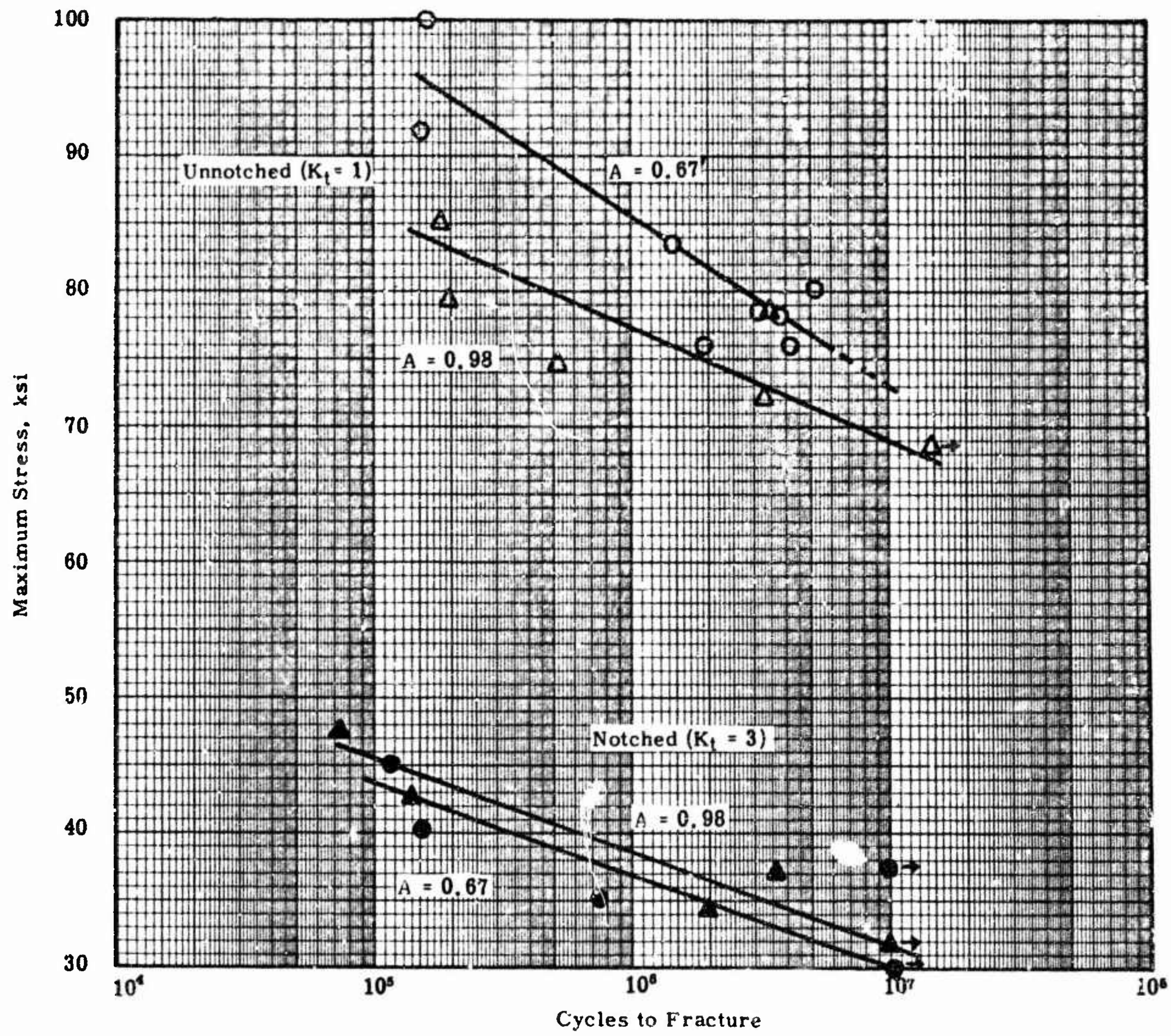


Figure 80. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Sheet at 70°F in the Notched and Unnotched Conditions.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

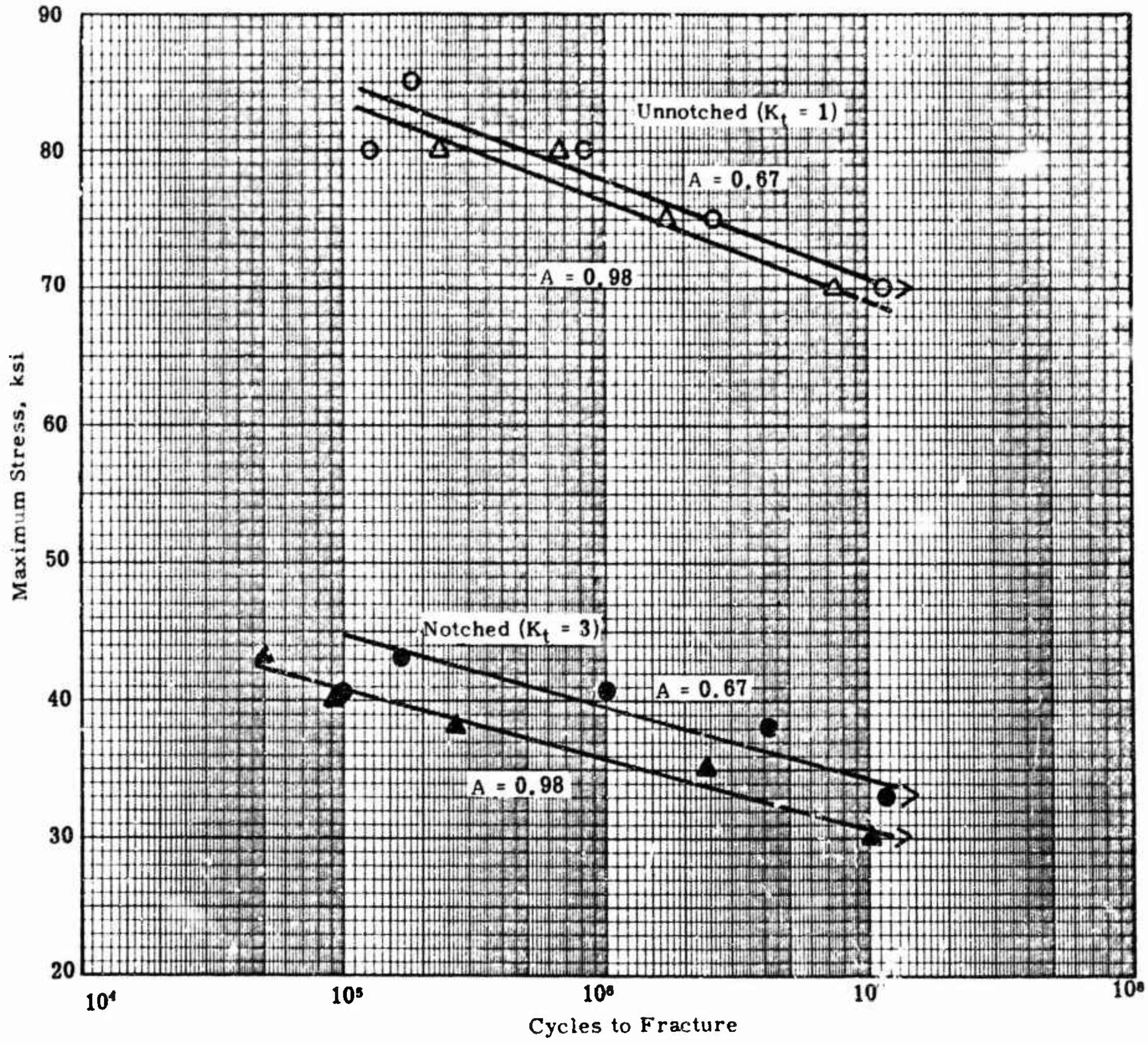


Figure 81. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Sheet at 400°F in the Notched and Unnotched Conditions.

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

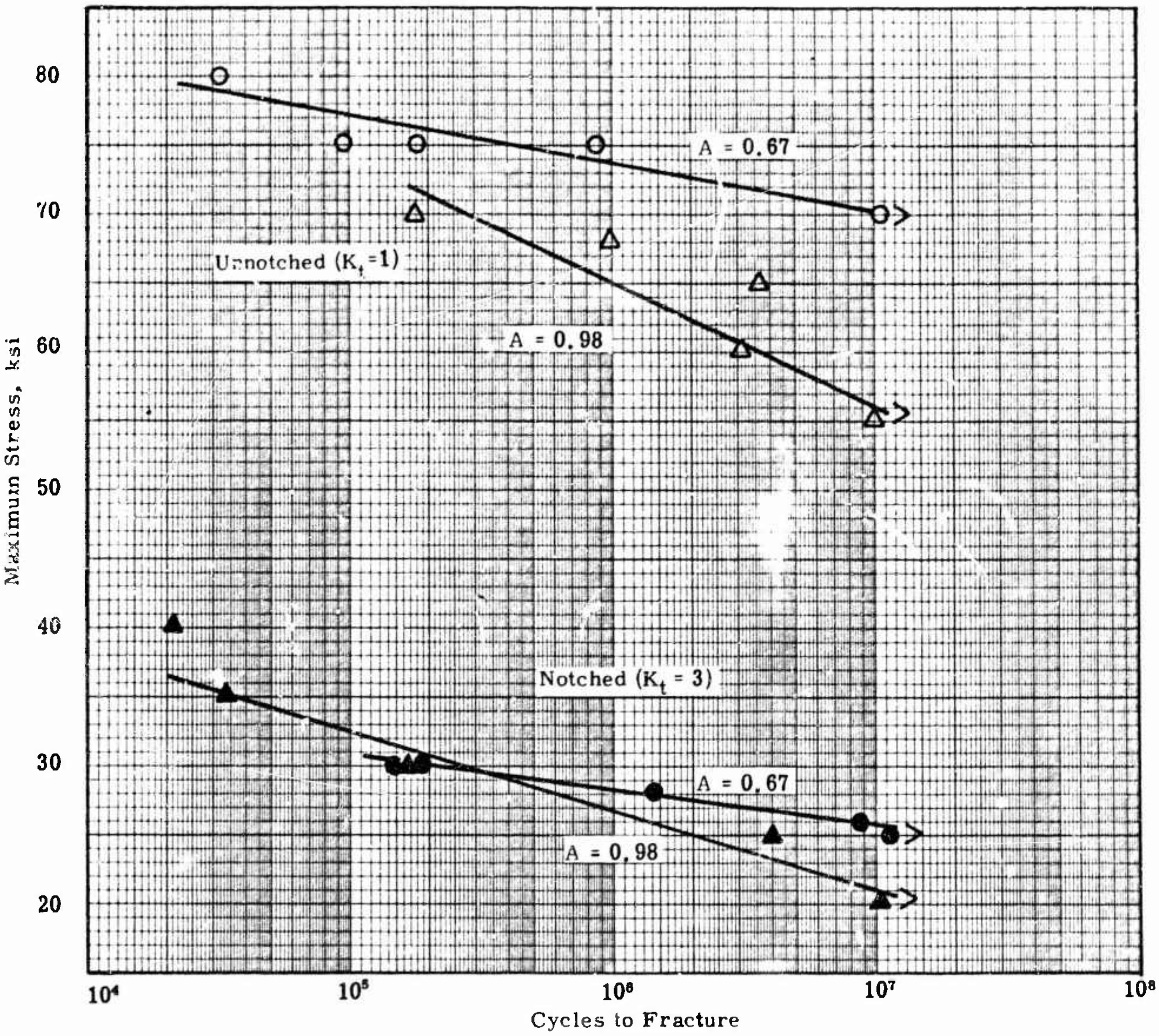


Figure 82. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Sheet at 800°F in the Notched and Unnotched Conditions

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

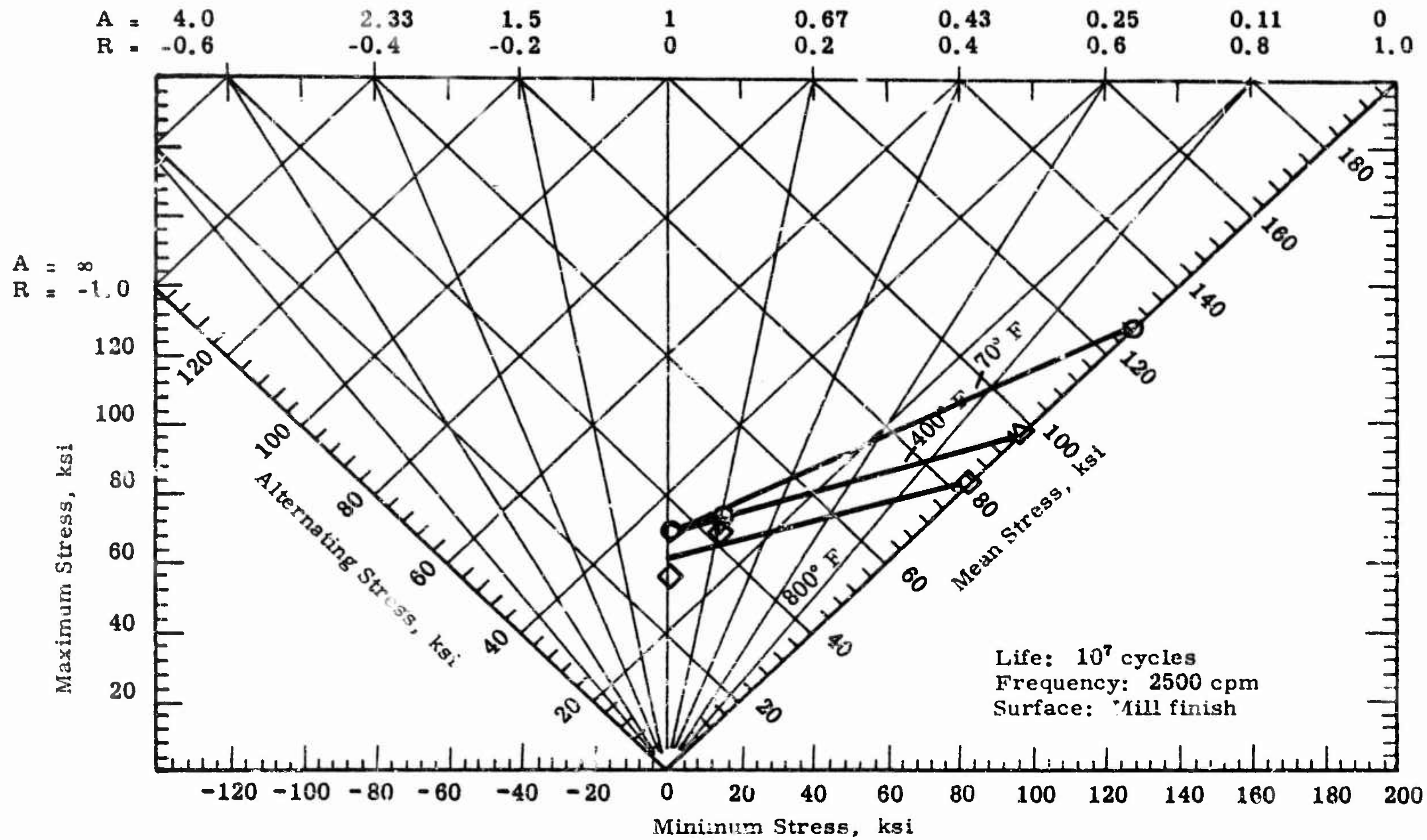


Figure 83. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr Alloy Sheet (Unnotched) at Different Temperatures

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.

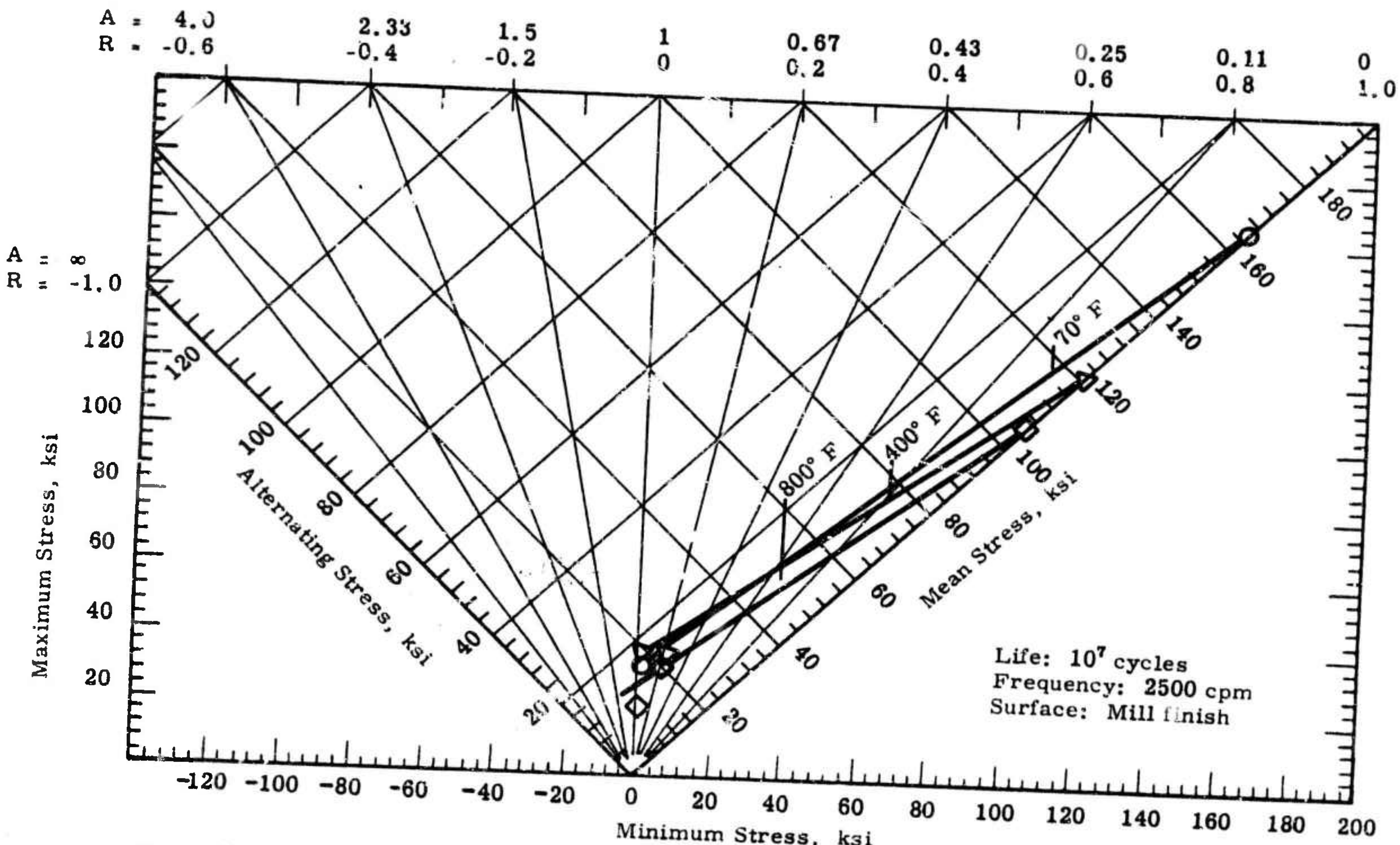


Figure 84. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr Alloy Sheet (Notched K_t = 3) at Different Temperatures

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 16 °F, 1/2 hr, A.C.

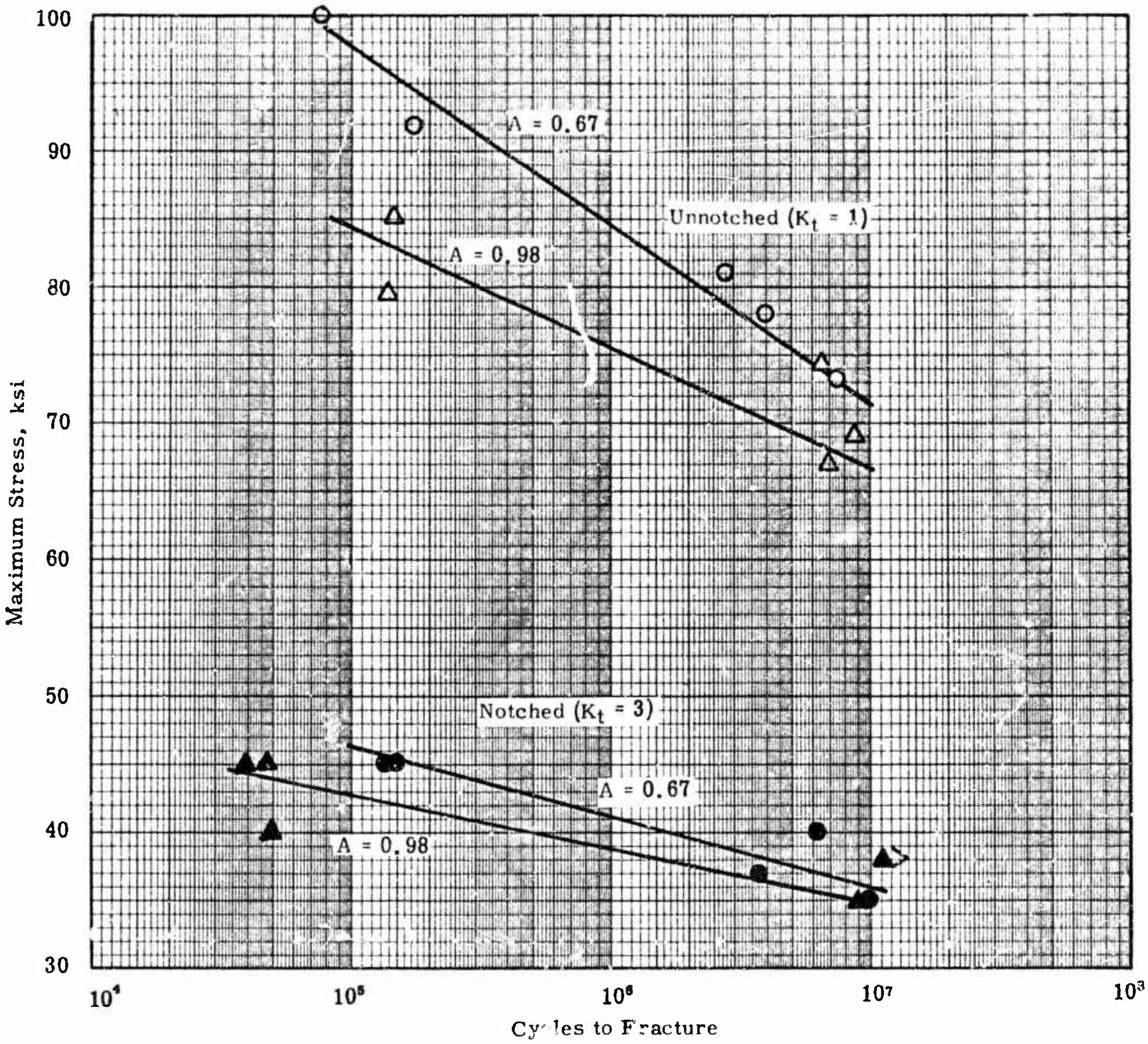


Figure 85. S-N Curves for the Ti-5Al-5Sn-5Zr-1V-1Mo Alloy Sheet at 70°F in the Notched and Unnotched Conditions

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550°F, 1/2 hr, A. C. + 1400°F, 1/4 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

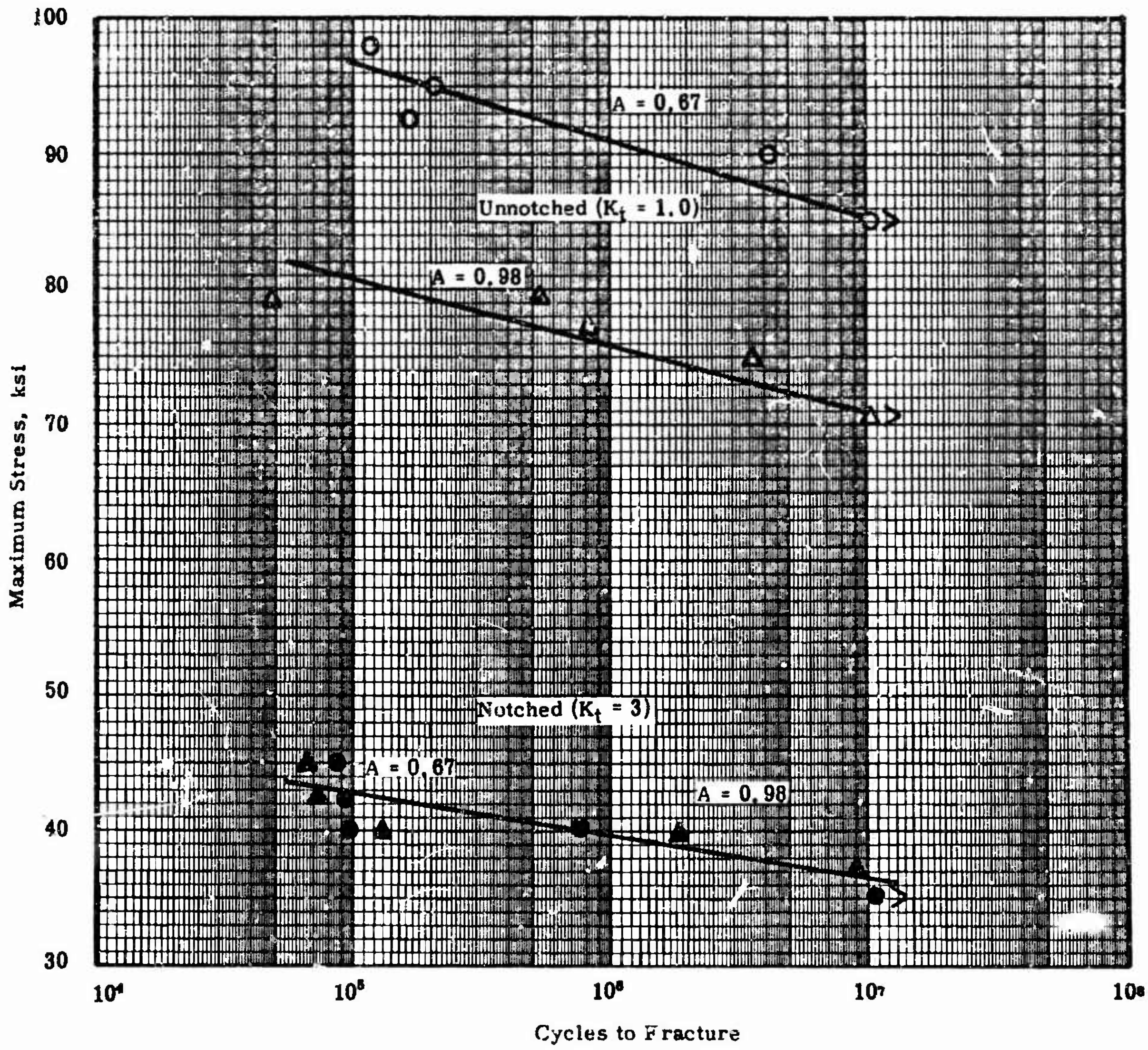


Figure 86. S-N Curves for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 400°F in the Notched and Unnotched Conditions.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550°F, 1/2 hr, A. C. + 1400°F, 1/4 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

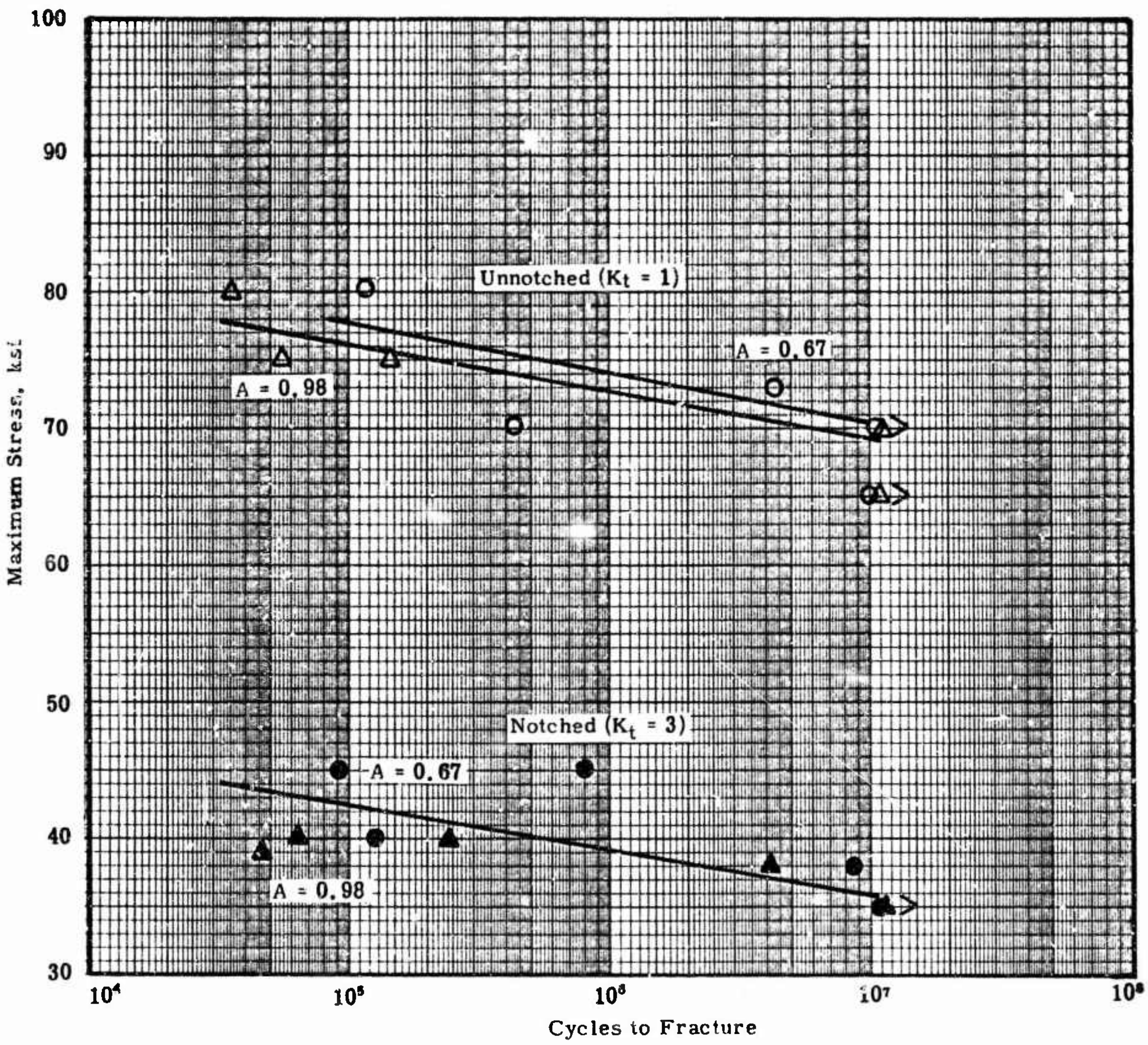


Figure 87. S-N Curves for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at 800°F in the Notched and Unnotched Conditions.

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550°F, 1/2 hr, A. C. + 1400°F, 1/4 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

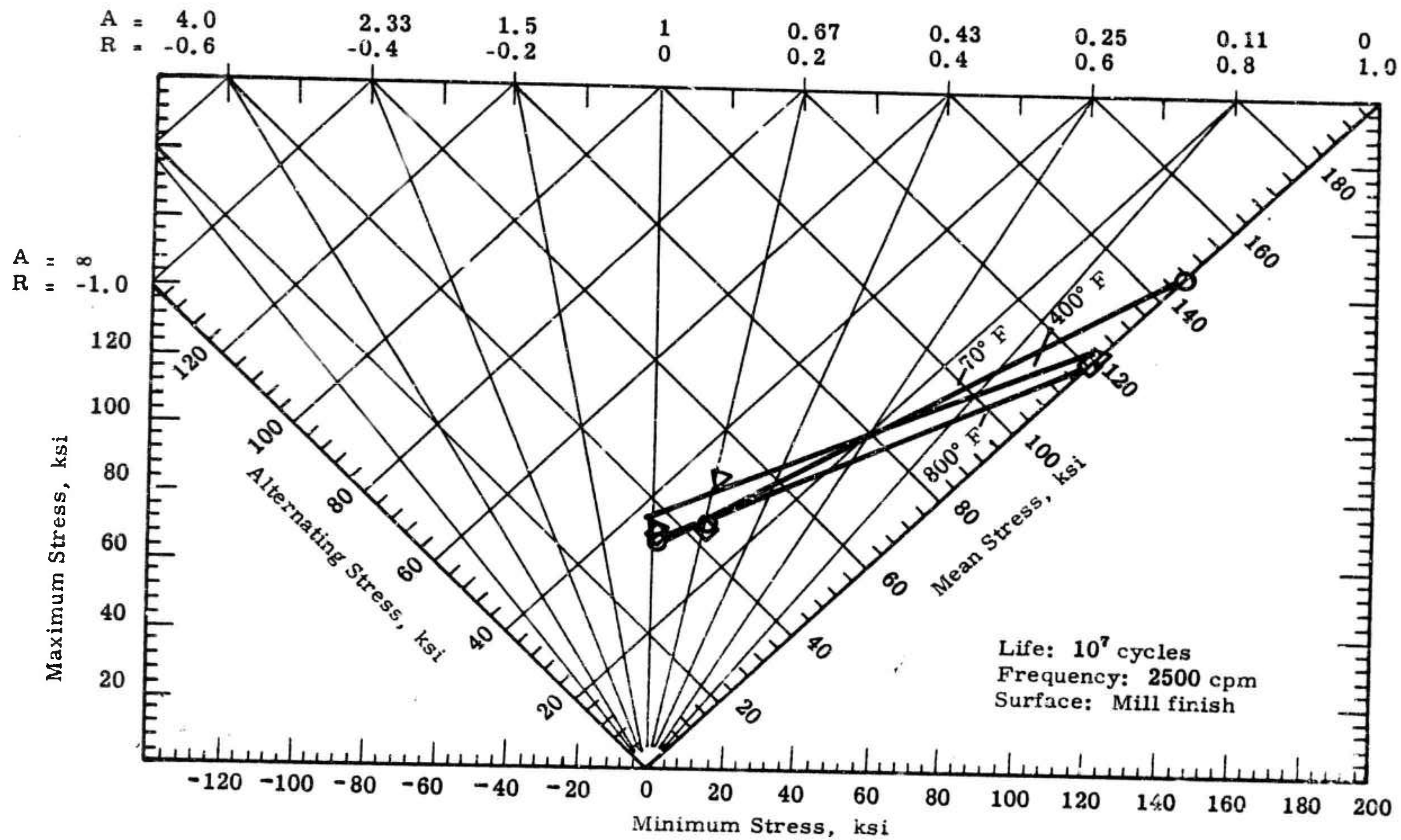


Figure 88. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet (Unnotched) at Different Temperatures

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

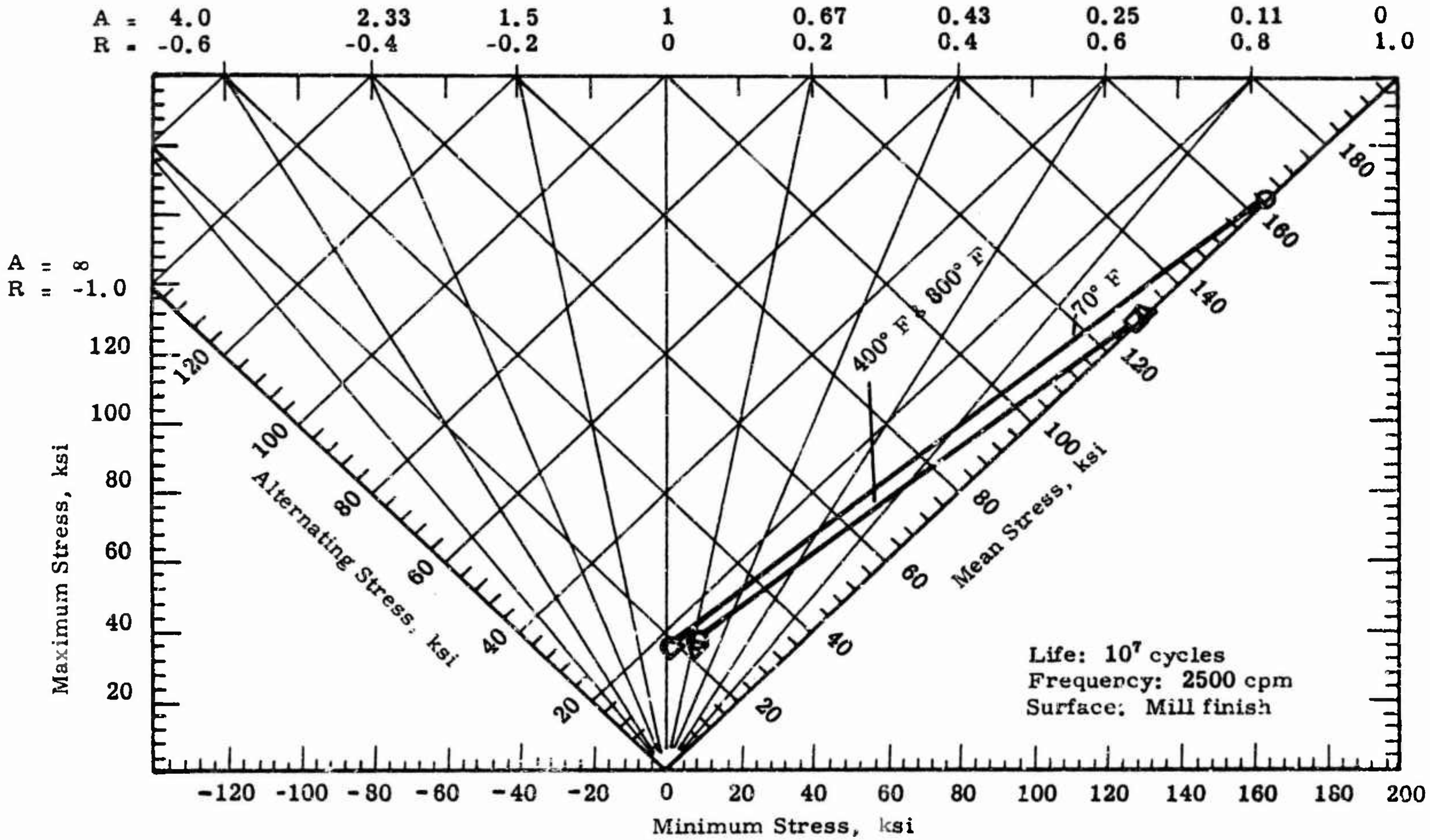


Figure 89. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet (Notched $K_t = 3$) at Different Temperatures

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

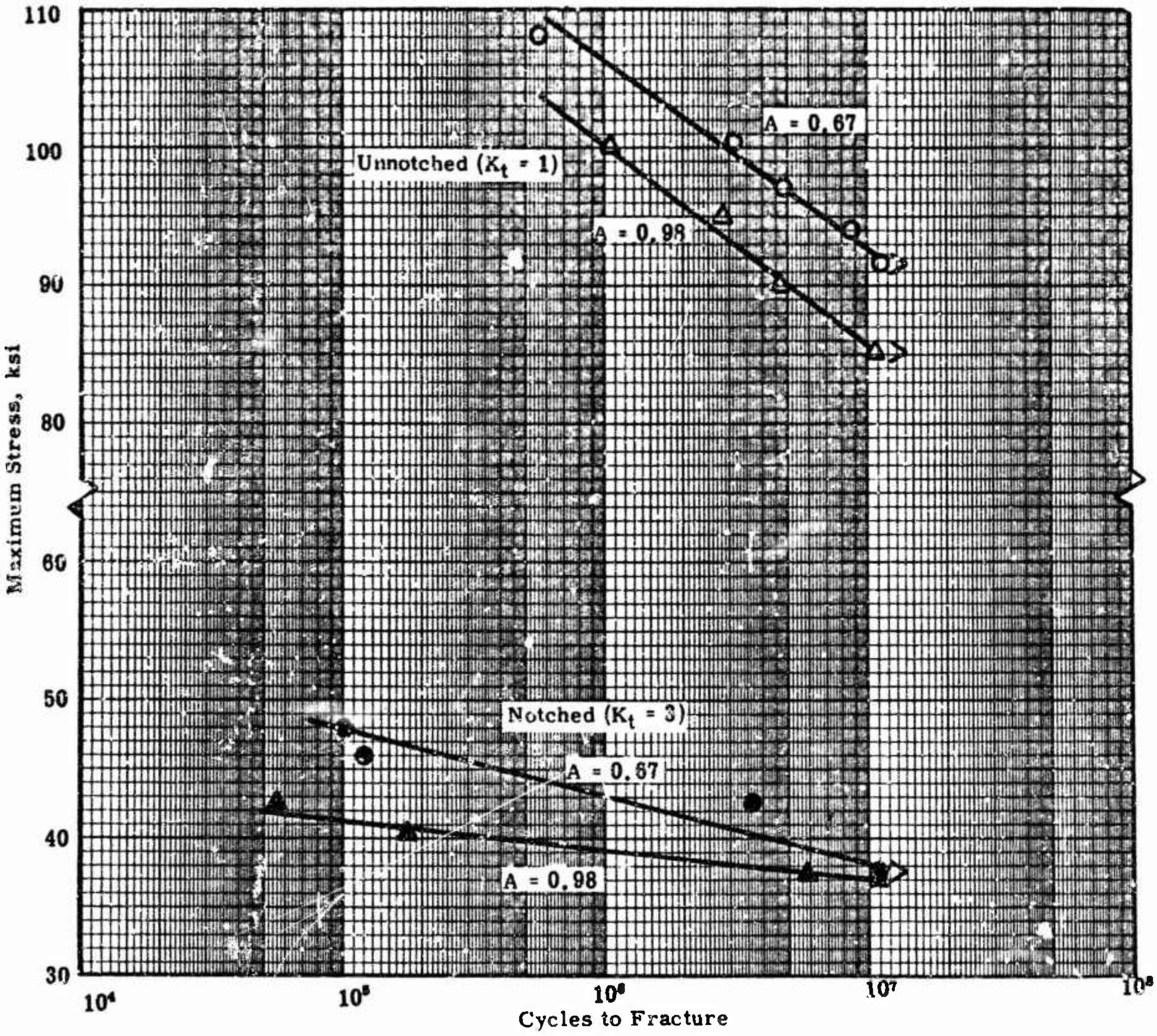


Figure 90. S-N Curves for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 70°F in the Notched and Unnotched Conditions.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C. + 1450°F, 1/4 hr. A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

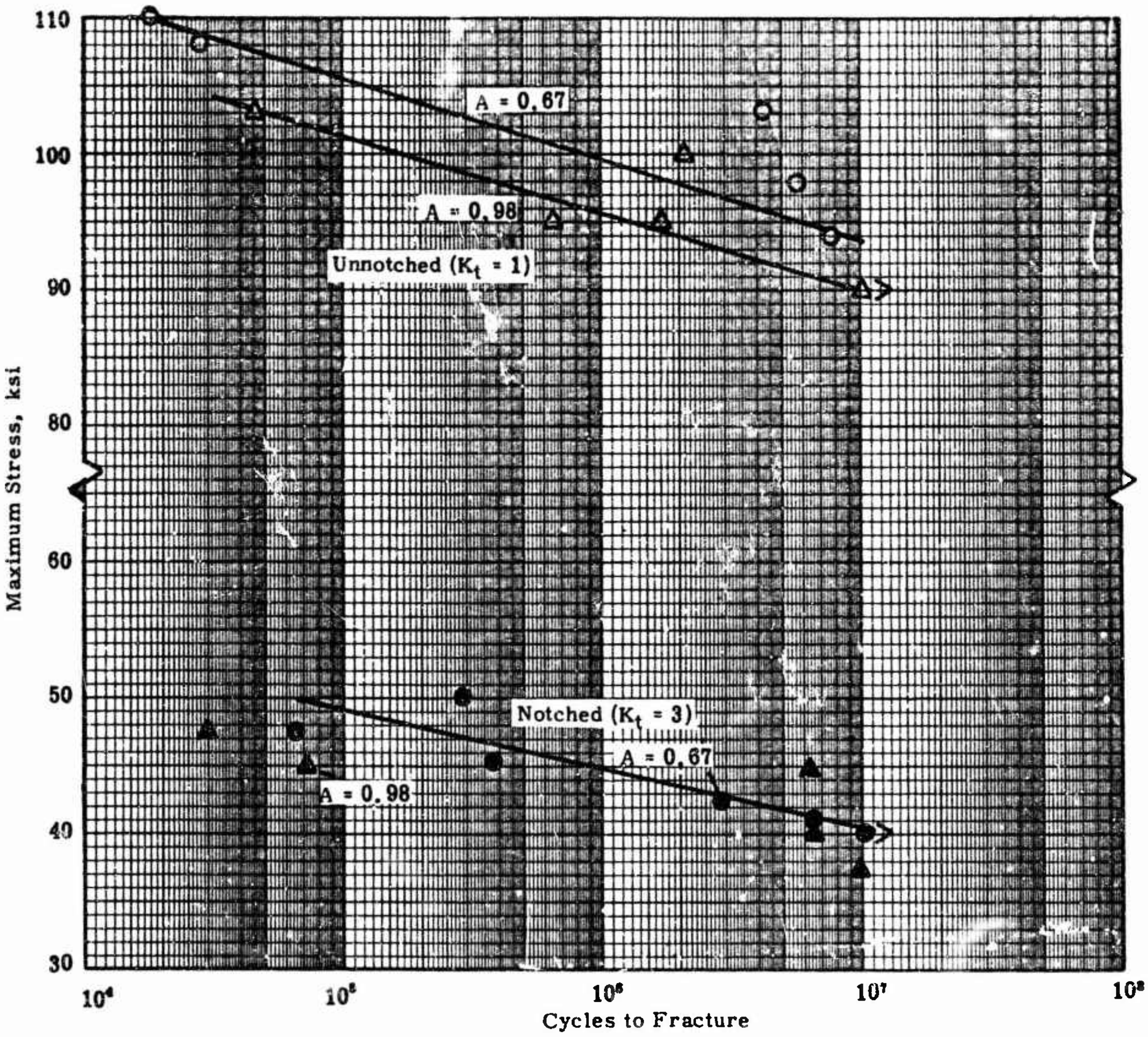


Figure 91. S-N Curves of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 400°F in the Notched and Unnotched Conditions.

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C. + 1450°F, 1/4 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

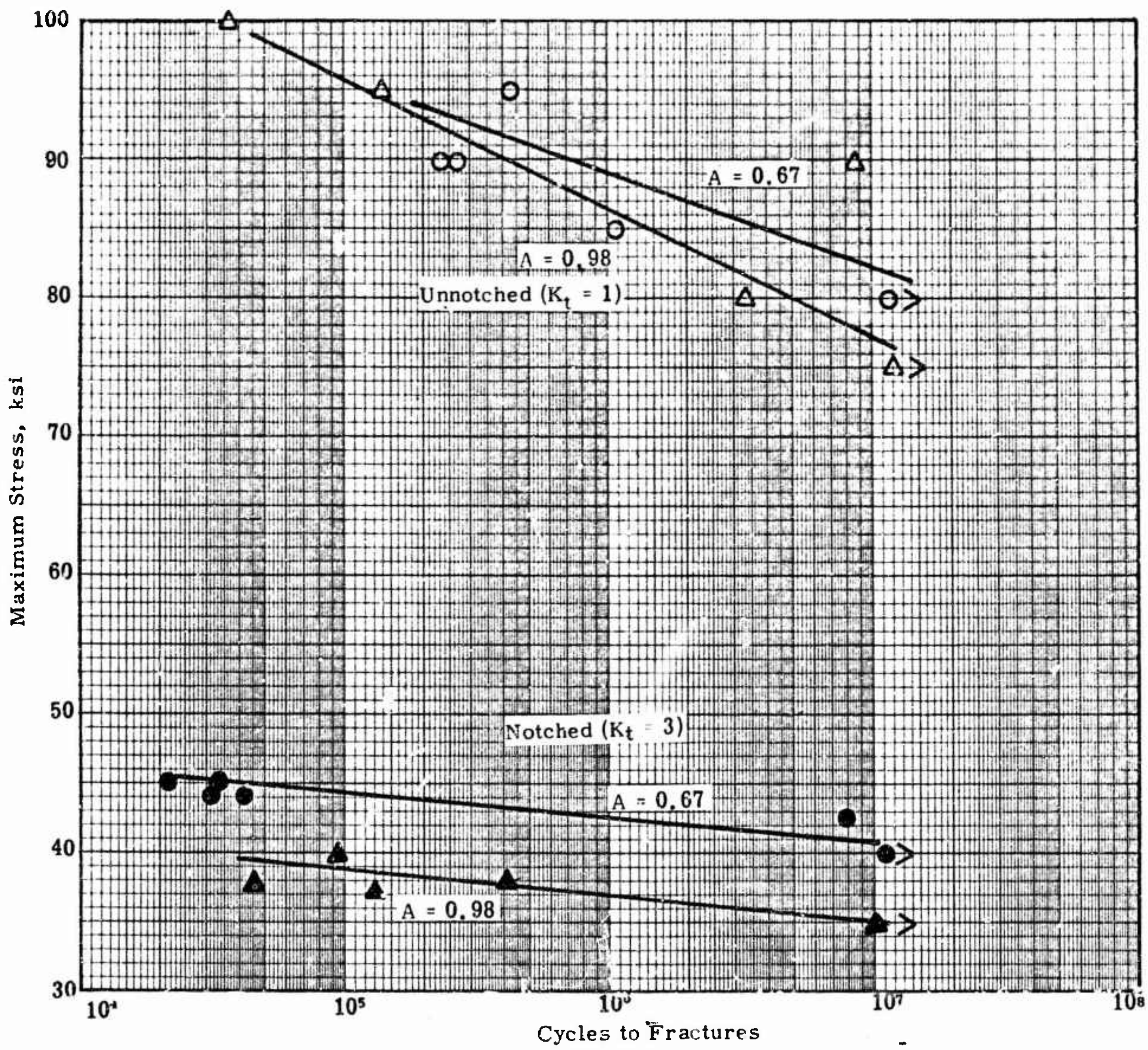


Figure 92. S-N Curves for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at 800°F in the Notched and Unnotched Conditions

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650°F, 1/2 hr, A. C. + 1450°F, 1/4 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

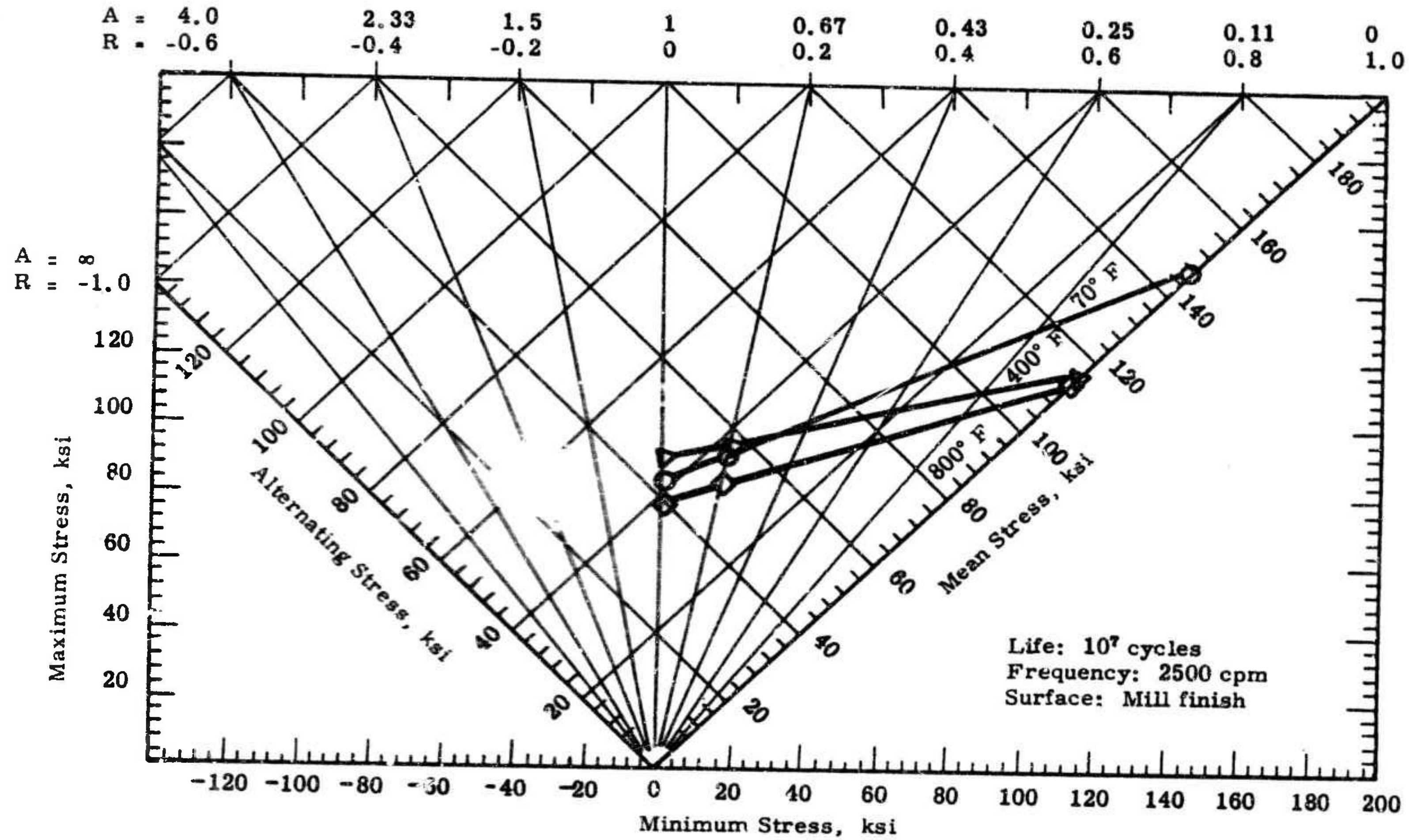


Figure 93. Constant-Life Fatigue Diagram for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet (Unnotched) at Different Temperatures

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

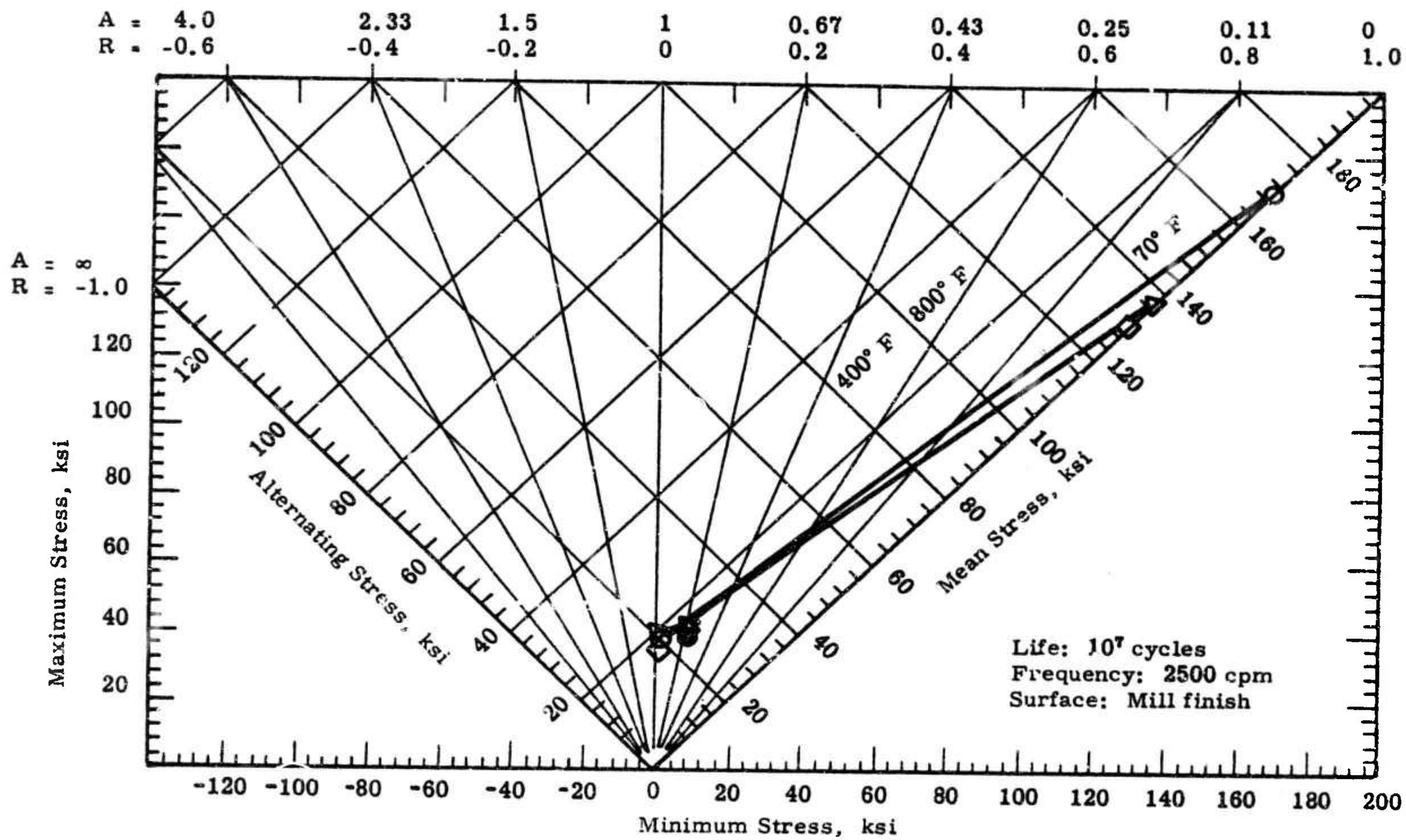


Figure 94. Constant-Life Fatigue Diagram for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet (Notched, $K_t = 3$) at Different Temperatures

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

Fracture Toughness

Fracture-toughness data for the sheet alloys are given in the following tables:

Alloy	Tables
Ti-5Al-5Sn-5Zr	19, 65, 66
Ti-5Al-5Sn-5Zr-1Mo-1V	19, 65, 66
Ti-6Al-2Sn-4Zr-2Mo	19, 65, 66

Tables with numbers underlined are in Appendix I

In most of the tests on the titanium sheet alloys, gross yielding occurred across the supporting section of the specimen in advance of the extension of the crack. Calculation of the fracture toughness parameters—K_c or K_{Ic}—in such instances leads to invalid results in that the values obtained from these calculations considerably underestimate the true fracture toughness of the material. This is so because the crack-tip plastic zone size is actually much larger than that provided for in the calculation for the fracture toughness parameters. A plastic zone correction term, which would not appreciably alter the results obtained, was not included in the equations for calculation of the fracture toughness. One criterion that has been used to judge the validity of fracture toughness measurements is the ratio of the net stress (calculated from the load used in the fracture toughness calculation) to the yield strength.[8] According to this criterion, the ratio (σ net/F_{ty}) should not exceed 0.8 for the calculated factor to be valid. As shown in Tables 65 and 66 the ratio was generally greater than 0.8 for the sheet alloys.

Stress-Corrosion

Data relating to the stress corrosion of the sheet alloys may be found in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	95, 96, 97	20, 67
Ti-5Al-5Sn-5Zr-1Mo-1V	98, 99, 100	20, 68
Ti-6Al-2Sn-4Zr-2Mo	101, 102, 103	20, 69

Tables with numbers underlined are in Appendix I

Results of the preliminary stress-corrosion tests to determine the minimum temperature at which stress corrosion would occur are summarized in Table 20. As this table shows, the lowest temperature at which stress-corrosion

Table 19

Summary of Apparent Fracture Toughness of the Sheet Alloys

Notice: Gross yielding occurred in tests at 400 and 70° F, and to some extent at -110° F, such that the true fracture toughness is not represented by data given in this table.

Alloy	Orien- tation	Temp., °F	K_{nc}[a] ksi $\sqrt{in.}$	K_c[b] ksi $\sqrt{in.}$
Ti-5Al-5Sn-5Zr	L	400	35.9	x
Ti-5Al-5Sn-5Zr	L	70	51.3	x
Ti-5Al-5Sn-5Zr	L	-110	61.5	118.2
Ti-5Al-5Sn-5Zr	T	400	35.7	x
Ti-5Al-5Sn-5Zr	T	70	48.9	x
Ti-5Al-5Sn-5Zr	T	-110	60.6	125.7
Ti-5Al-5Sn-5Zr-1Mo-1V	L	400	44.5	x
Ti-5Al-5Sn-5Zr-1Mo-1V	L	70	57.2	97.5
Ti-5Al-5Sn-5Zr-1Mo-1V	L	-110	64.8	109.0
Ti-5Al-5Sn-5Zr-1Mo-1V	T	400	46.3	x
Ti-5Al-5Sn-5Zr-1Mo-1V	T	70	56.0	95.6
Ti-5Al-5Sn-5Zr-1Mo-1V	T	-110	52.7	107.9
Ti-6Al-2Sn-4Zr-2Mo	L	400	48.6	x
Ti-6Al-2Sn-4Zr-2Mo	L	70	59.1	106.5
Ti-6Al-2Sn-4Zr-2Mo	L	-110	63.3	114.3
Ti-6Al-2Sn-4Zr-2Mo	T	400	41.5	x
Ti-6Al-2Sn-4Zr-2Mo	T	70	55.8	99.7
Ti-6Al-2Sn-4Zr-2Mo	T	-110	62.6	107.9

a Stress intensity factor reported as K_{nc}, rather than as K_{Ic}, because pop-in was not observed and calculation was based on load deviation from linearity.

b "x" denotes that K_c could not be calculated because of gross slow crack extension of the specimen.

Table 20

Results of Preliminary Tests to Establish the Susceptibility Temperature for NaCl Stress-Corrosion for the Sheet Alloys

Ti-5Al-5Sn-5Zr Alloy			Ti-5Al-5Sn-5Zr-1Mo-1V Alloy			Ti-6Al-2Sn-4Zr-2Mo Alloy		
Exposure Temp, ° F	Exposure Time, hr	Embrittled	Exposure Temp, ° F	Exposure Time, hr	Embrittled	Exposure Temp, ° F	Exposure Time, hr	Embrittled
450	100	No	450	100	No	450	100	No
450	457	No	450	200	No	450	200	No
450	457	No	450	457	No	450	457	No
			450	457	No	450	457	No
550	100	No	450	457	No	450	457	No
550	100	No						
550	505	No	500	100	Yes	500	100	No
550	987	No	500	100	Yes	500	100	Yes
550	987	No				500	100	No
			550	100	Yes	500	265	Yes
600	120	No	550	100	Yes	500	265	Yes
600	120	No						
600	333	No				550	100	Yes
600	600	Yes				550	100	Yes
600	600	Yes						
600	600	Yes						
650	100	Yes						
650	100	Yes						

embrittlement occurred was 500° F for the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alloys and 600° F for the Ti-5Al-5Sn-5Zr alloy.

The residual yield and tensile strength of the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alpha-beta alloys are summarized in Figures 98 and 101, where these properties are shown as a function of the time-temperature parameter, $T(20 + \log t)10^{-3}$, in which T is the exposure temperature in degrees Rankine and t is the exposure time in hours. This parameter was arbitrarily chosen for presentation of the data on the logic that stress-corrosion is a temperature-time rate phenomenon. As these figures show, the strength properties of these alloys did not decrease as a direct function of the severity of the stress-corrosion environment (time-temperature) except in those instances (shown by shaded data points on the graphs) where the stress-corrosion attack was so severe that fracture in thetensile tests occurred at very low deformation levels. The data in Figures 98 and 101 indicate that the residual yield strength of the Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo alloys decreased as a function of the exposure stress. In contrast, both the yield and tensile strengths of the all-alpha alloy decreased appreciably with the more severe exposure conditions and there was no apparent relationship between the residual strength and the exposure stress, as may be seen in Figure 95. As Figures 96, 99, and 102 show, the residual tensile ductility decreased as the stress-corrosion time and temperature increased. The photomicrographs in Figures 97, 100 and 103 show representative examples of the corrosive attack on each alloy at different stress-corrosion conditions. Photomicrographs were not obtained for conditions where visible evidence of corrosion was not found in microscopic examination of samples.

Dynamic Modulus

Figure 104 and Table 21 show the average dynamic moduli for longitudinal and transverse directions of the sheet alloys as functions of temperature. The dynamic moduli decreased with temperature to about the same level observed in the tensile tests (11×10^6 psi to 12×10^6 psi at 1000° F).

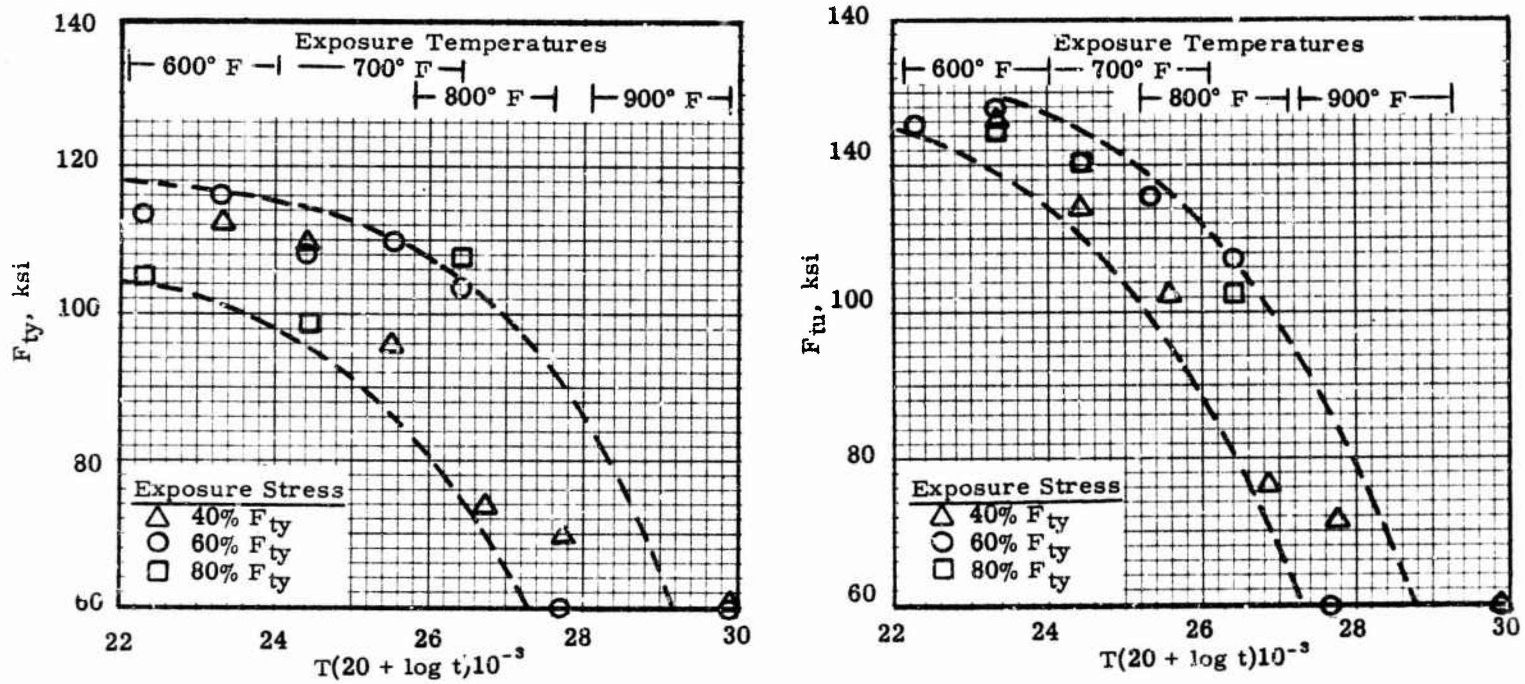


Figure 95. Tensile Properties at Room Temperature of Ti-5Al-5Sn-5Zr Alloy Sheet after Stress-Corrosion Exposure at Different Times, Temperatures and Stresses to Dry Salt

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.

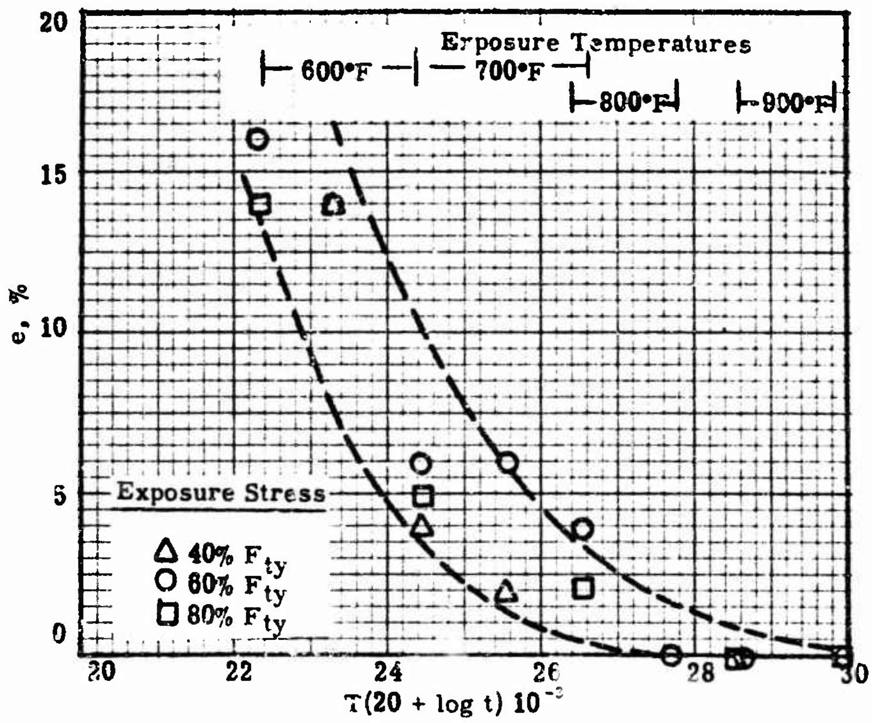
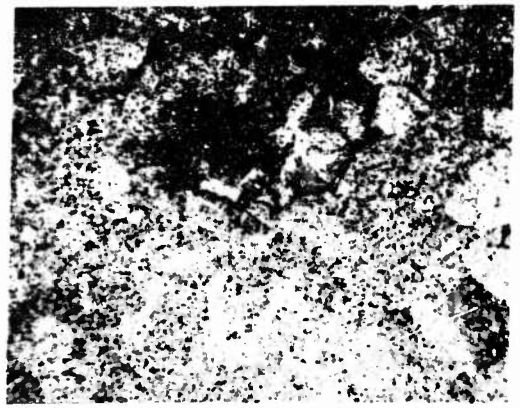
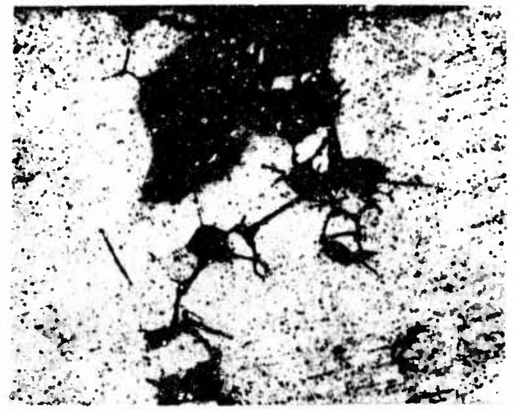


Figure 96. Ductility of the Ti-5Al-5Sn-5Zr Alloy Sheet After Stress-Corrosion Exposure at Different Times, Temperature and Stresses to Dry Salt

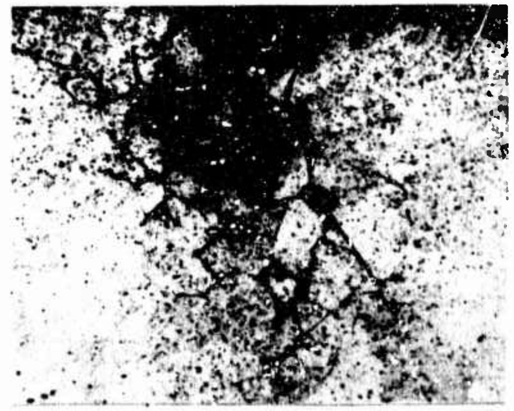
Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650°F, 2 hr, A. C.



700° F, 100 hr, 60% F_{ty}

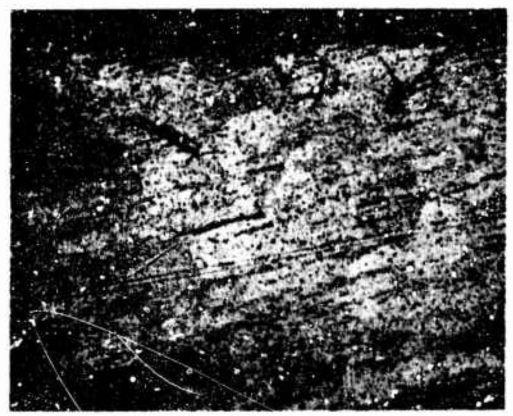


800° F, 100 hr, 60% F_{ty}



900° F, 100 hr, 60% F_{ty}

600° F, 100 hr, 60% F_{ty}



600° F, 1000 hr, 40% F_{ty}

Figure 97. Stress-Corrosion Damage in the Ti-5Al-5Sn-5Zr Alloy Sheet after Exposure to Different Temperature-Time-Stress Conditions

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.
All samples etched in 1 ml Hf + 2 ml HNO_3 + 98 ml H_2O and photographed at 250X.

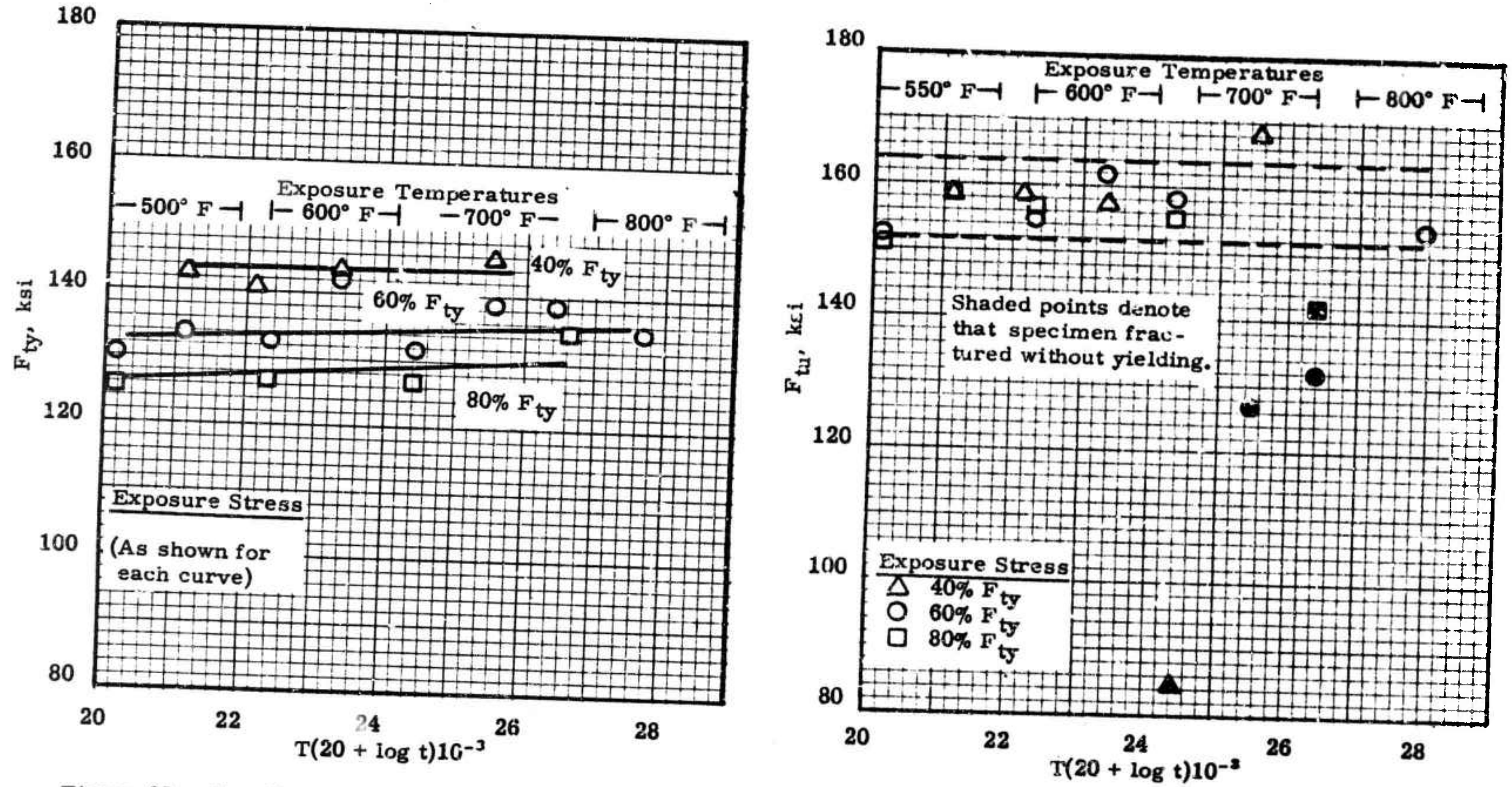


Figure 98. Tensile Properties at Room Temperature of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet after Stress-Corrosion Exposure at Different Times, Temperatures and Stresses to Dry Salt

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

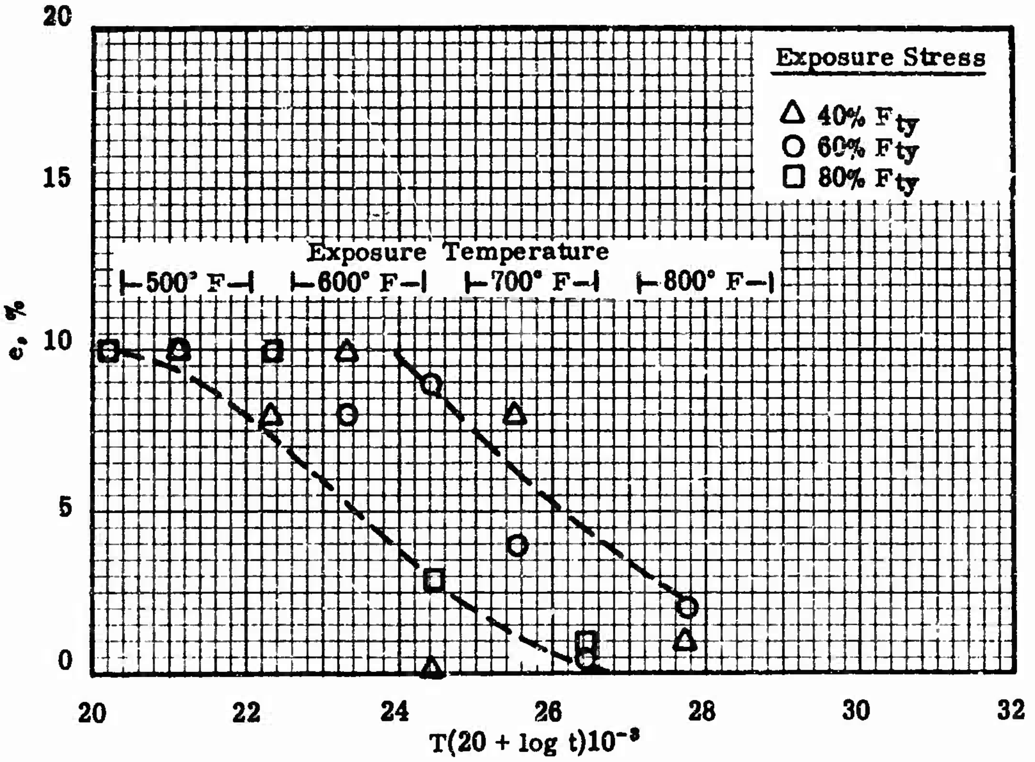
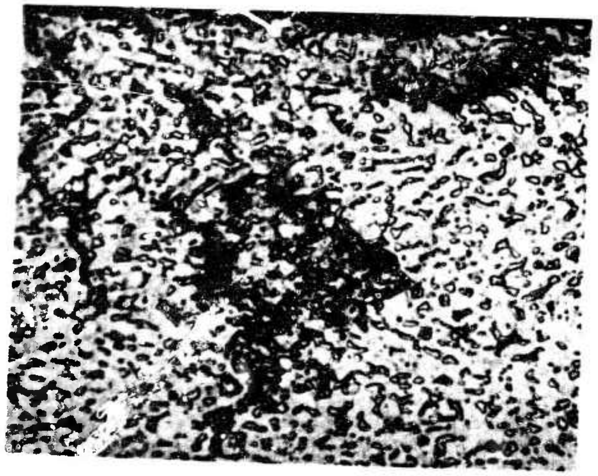
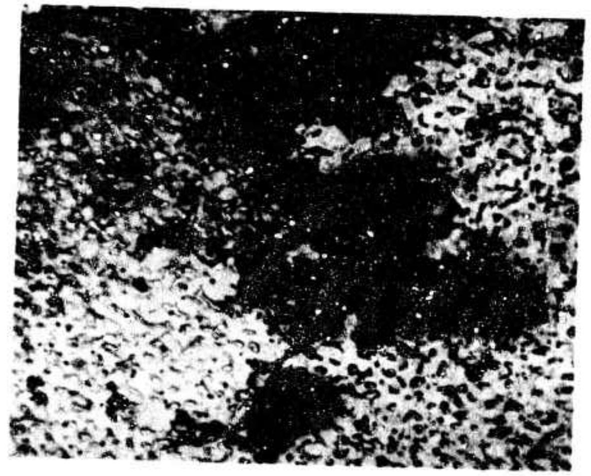


Figure 99. Ductility of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet after Stress-Corrosion Exposure at Different Times, Temperatures, and Stresses to Dry Salt.

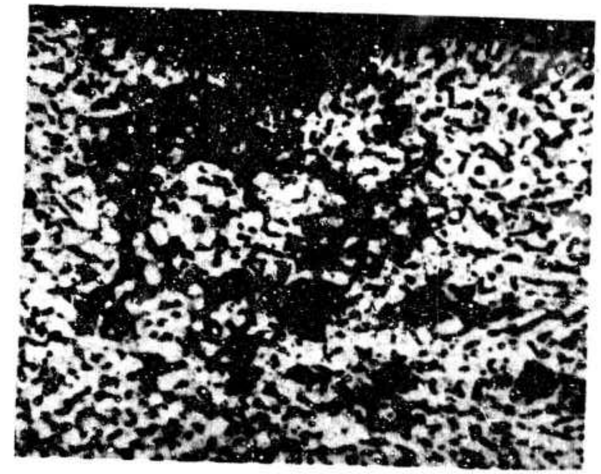
Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.



600° F, 1000 hr, 40% F_{tv}



700° F, 100 hr, 60% F_{ty}



800° F, 100 hr, 60% F_{ty}

Figure 100. Stress-Corrosion Damage in the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet after Exposure to Different Temperature-Time-Stress Conditions

Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
All samples etched in 1 ml Hf + 2 ml HNO_3 + 98 ml H_2O and photographed at 750X.

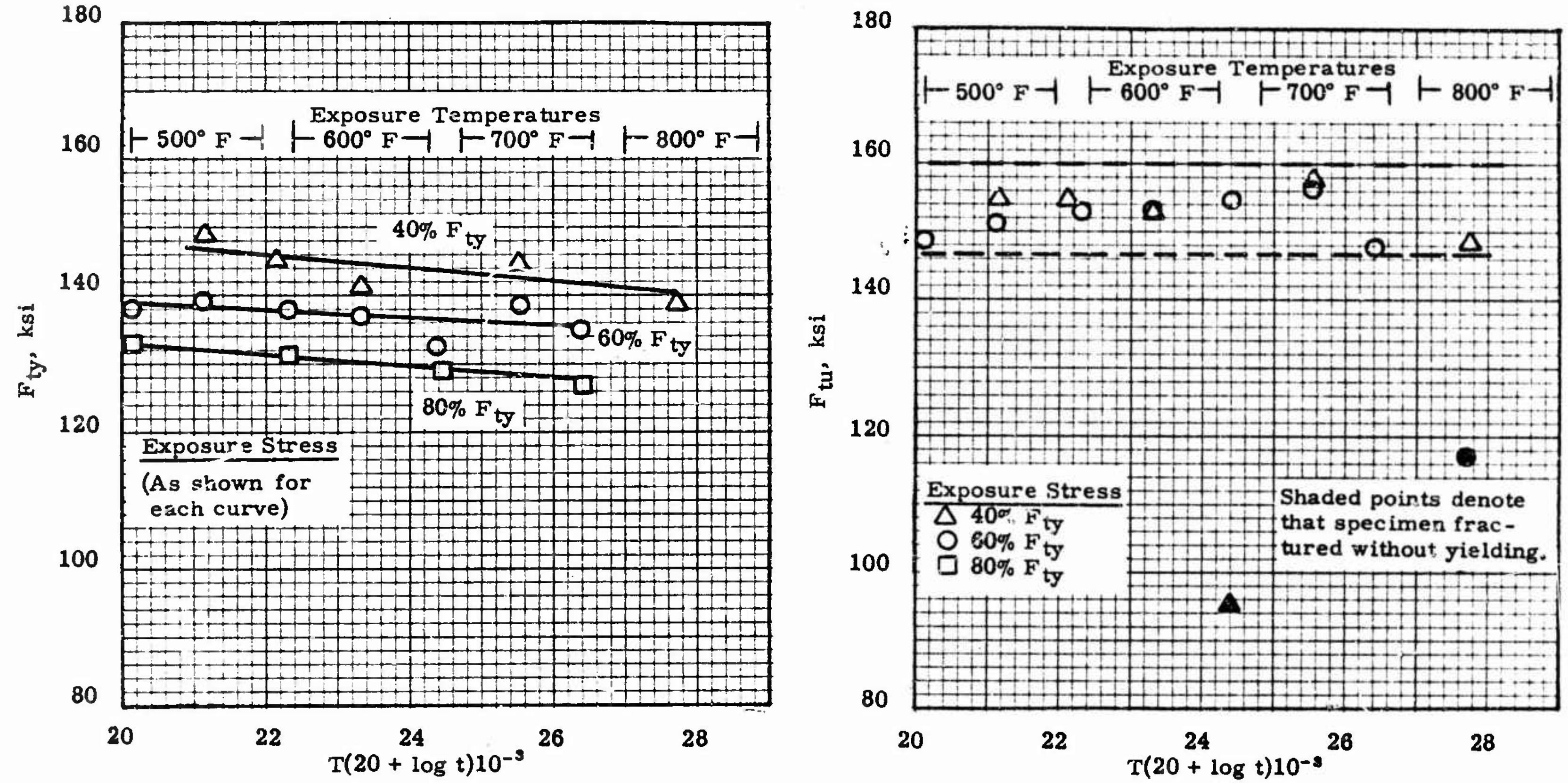


Figure 101. Tensile Properties at Room Temperature of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet after Stress-Corrosion Exposure at Different Times, Temperatures and Stresses to Dry Salt

Heat No. V-3016
Thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A. C.

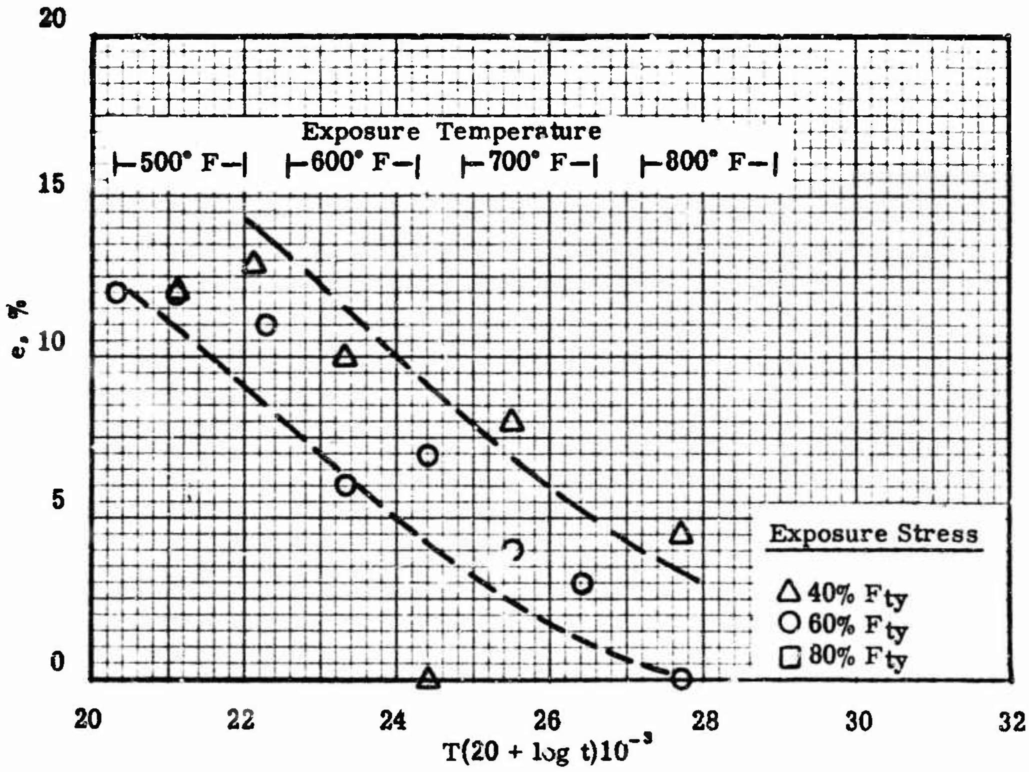
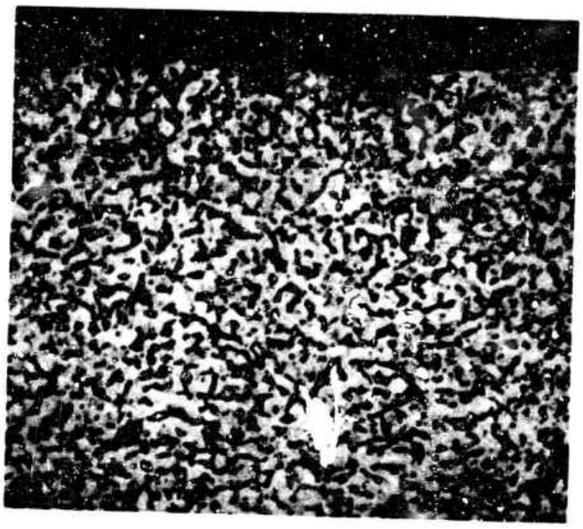
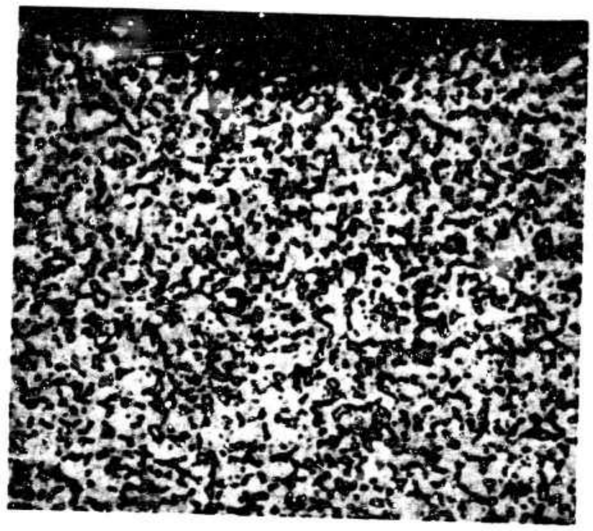


Figure 102. Ductility of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet After Stress-Corrosion Exposure at Different Times, Temperatures, and Stresses to Dry Salt.

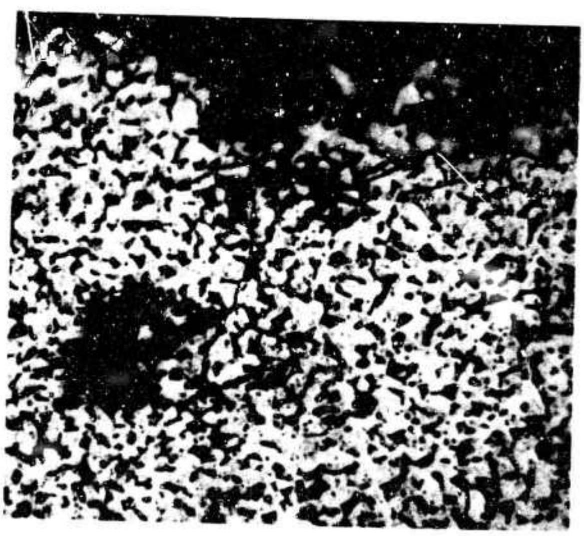
Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



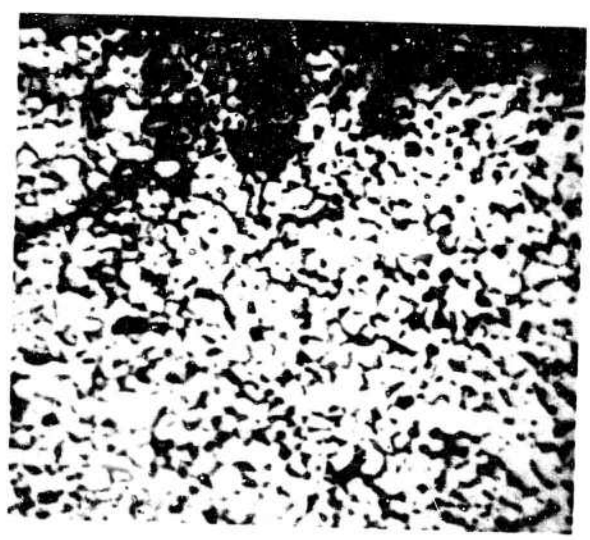
600° F, 100 hr, 60% F_{ty}



600° F, 1000 hr, 40% F_{ty}



700° F, 100 hr, 60% F_{ty}



800° F, 100 hr, 60% F_{ty}

Figure 103. Stress-Corrosion Damage to the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet after Exposure to Different Temperature-Time-Stress Conditions

Heat No. V-3016
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.
All specimens etched in 1 ml Hf + 2 ml HNO_3 + 98 ml H_2O and photographed at 750X.

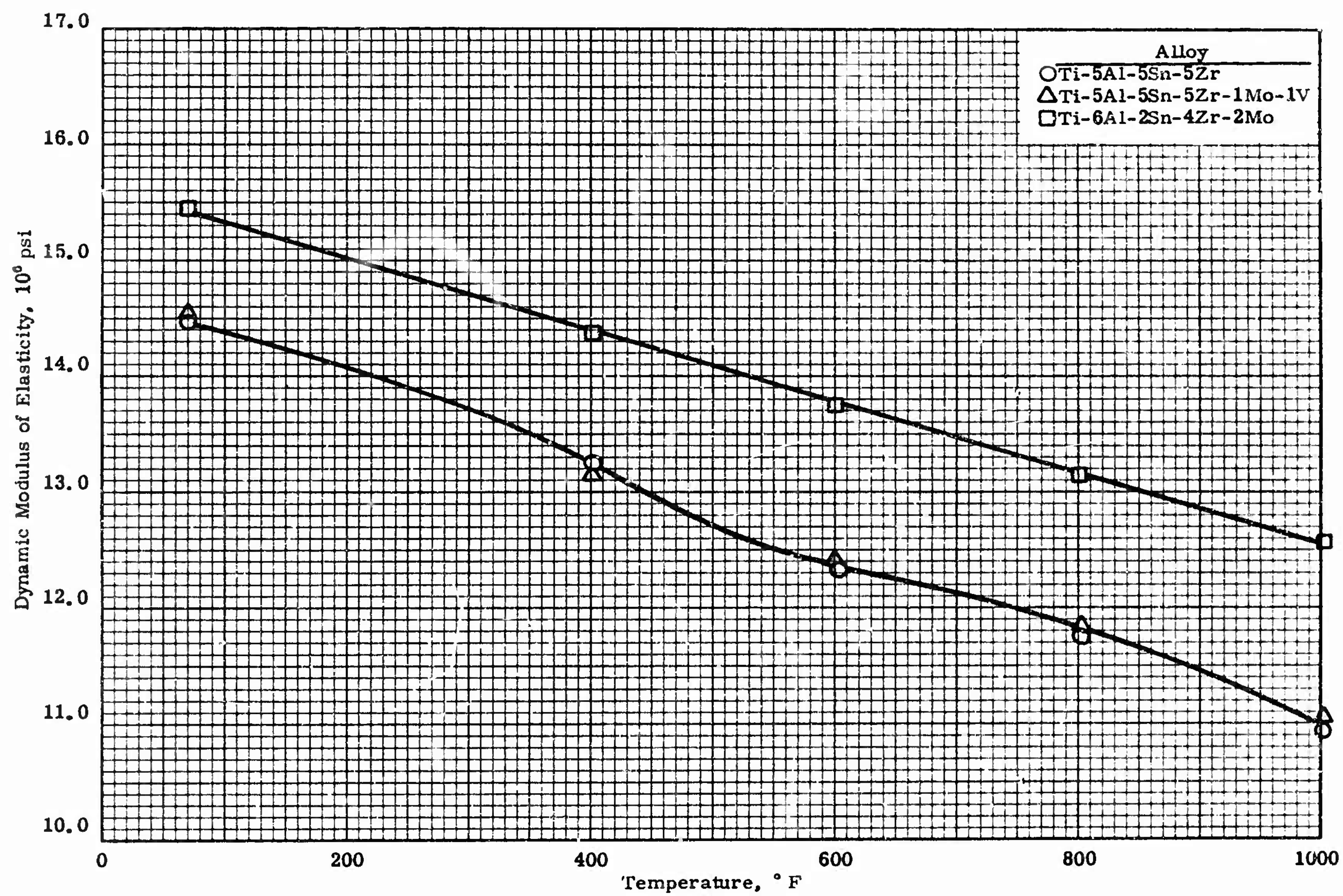


Figure 104. The Effect of Temperature on the Moduli of Elasticity of the Titanium Sheet Alloys under Dynamic Loading Conditions.

Table 21

The Dynamic Moduli of Elasticity at Different Temperatures of Three Titanium Alloys in the Form of Forty-Mil Sheet

Alloy	E, 10^6 psi				
	70° F	400° F	600° F	800° F	1000° F
Ti-5Al-5Sn-5Zr[a]	14.45	13.25	13.32	11.76	10.92
Ti-5Al-5Sn-5Zr-1Mo-1V[b]	14.52	13.16	12.42	11.86	11.07
Ti-6Al-2Sn-4Zr-2Mo[c]	15.46	14.39	13.75	13.14	12.58

[a] Heat No. D-8060, Heat treatment: 1650° F, 1/2 hr, A.C.

[b] Heat No. V-2957, Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

[c] Heat No. V-3016, Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

Bar Alloys

Tensile

The following tables and figures show results of tensile tests on the bar alloys:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	105, 106, 107, 111, 112, 113	22, 24, 25, 70, 71, 74
Ti-679	108, 109, 110, 111, 112, 113	23, 24, 25, 72, 73, 74

Tables with numbers underlined are in Appendix I

As Figures 111 and 112 show, the tensile strength properties of the alpha-beta Ti-679 alloy are considerably higher than those of the all-alpha Ti-5Al-5Sn-5Zr alloy bar up to 1000° F. The strength properties of the Ti-679 alloy were also greater than those of the comparative alpha-beta alloy (Ti-6Al-4V), and the Ti-5Al-5Sn-5Zr alloy bar had higher strength than the comparative all-alpha alloy (Ti-5Al-2.5Sn).

Table 24 shows the results of the precision-modulus-of-elasticity measurements on the bar alloys at room temperature. The results of these tests and the modulus of elasticity as measured from the recorded stress-strain curves in the tensile tests indicate that the modulus of elasticity of the Ti-679 alloy at room temperature may be slightly higher than that of the Ti-5Al-5Sn-5Zr alloy.

Results of notched tensile tests on the bar alloys are given in Table 25.

Compression

The tables and figures listed below show data on the compression properties of the two bar alloys:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	114, 115, 117	26, 75
Ti-679	114, 116, 117	26, 76

Tables with numbers underlined are in Appendix I

Compression data given in Figure 117 for the two bar alloys evaluated in this program show that the Ti-679 bar has higher compressive strength than the Ti-6Al-4V alloy selected for comparison.

Table 22

Summary of the Averages and Standard Deviations for the Tensile Properties of the Ti-5Al-5Sn-5Zr Alloy Bar at Different Temperatures[a, b, c]

Heat No. D-8060

Temp.	F_{ty}, ksi		F_{tu}, ksi		e, %		R.A., %		E_t, 10^6 psi	
°F	Avg.	s	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	122.0	0.9	130.1	1.4	16.0	0.9	38.6	2.4	16.5	0.5
400	80.4	0.7	94.8	0.9	20.5	1.6	44.6	1.8	15.4	0.9
600	67.8	1.6	86.2	0.9	21.1	2.1	46.8	2.3	14.6	1.6
800	59.8	1.9	79.9	0.9	28.4	1.5	51.1	1.7	13.3	0.8
1000	58.1	1.6	75.8	0.8	22.8	1.1	51.2	1.5	11.9	0.6

Heat No. D-1793

Temp.	F_{ty}, ksi		F_{tu}, ksi		e, %		R.A., %		E_t, 10^6 psi	
°F	Avg.	s	Avg.	s	Avg.	s	Avg.	s	Avg.	s
70	116.5	1.4	122.7	1.2	17.1	1.2	40.1	1.0	16.6	0.2
400	81.3	0.8	95.5	0.3	21.3	0.5	45.8	0.8	16.7	1.6
600	67.7	0.6	87.8	0.6	23.3	0.5	49.1	0.7	14.5	1.1
800	61.6	0.4	81.4	0.5	27.3	0.5	52.2	0.8	14.5	1.1
1000	59.9	0.5	77.7	0.4	22.7	0.7	52.5	0.9	12.1	1.0

a Averages and standard deviations are based on 10 evaluations at each temperature.
b Heat treatment: 1650° F, 2 hr, A.C.
c Section size: 1/2 in. x 1-1/8 in.

Table 23

Summary of the Averages and Standard Deviations for the Tensile Properties of the Ti-679 Alloy Bar at Different Temperatures[a, b, c]

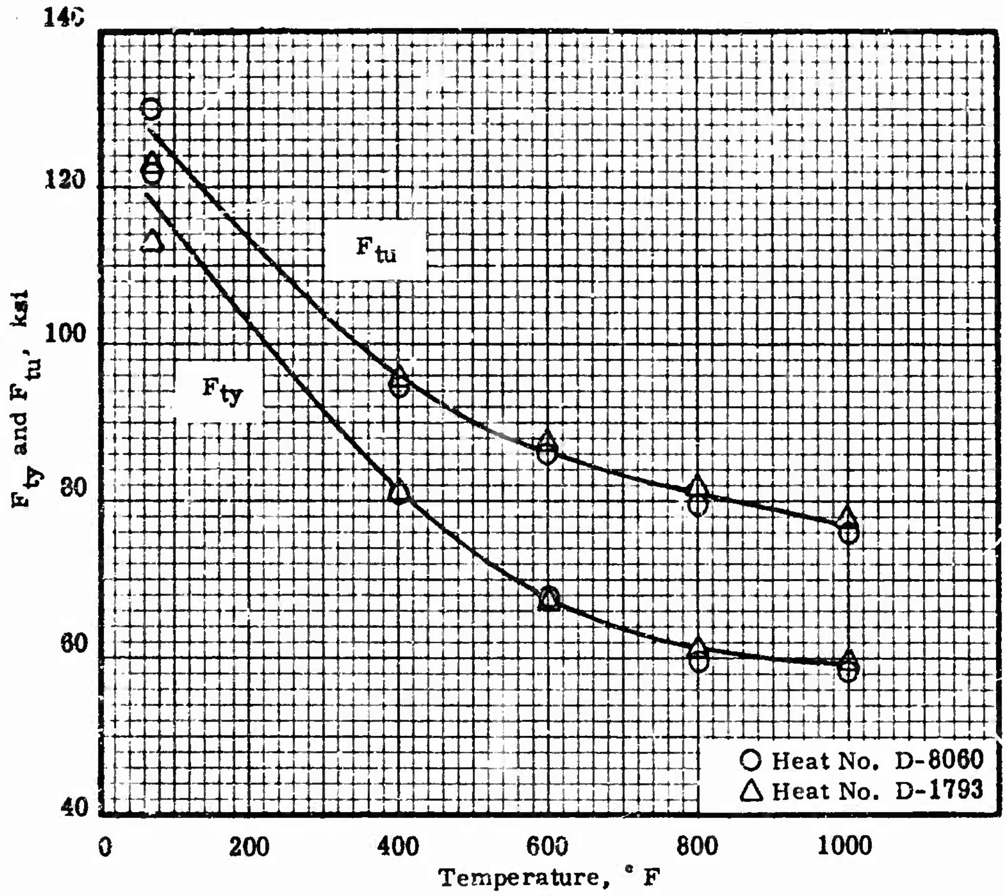
Heat No. D-7374

Temp. °F	F_{ty}, ksi Avg.	s	F_{tu}, ksi Avg.	s	e, % Avg.	s	R. A., % Avg.	s	E_t, 10^6 psi Avg.	s
70	138.6	2.[illegible]	148.6	1.9	14.4	0.5	42.9	2.4	15.2	0.3
400	100.3	2.4	121.5	2.3	15.7	1.2	48.8	1.9	14.6	0.8
600	89.8	1.7	114.1	1.9	13.9	0.7	48.9	3.4	13.7	0.6
800	83.1	1.8	108.8	1.7	15.4	0.9	49.2	2.1	13.3	0.4
1000	77.4	2.0	99.7	1.9	17.3	0.7	56.5	4.[illegible]	12.3	0.7

Heat No. D-8427

Temp. °F	F_{ty}, ksi Avg.	s	F_{tu}, ksi Avg.	s	e, % Avg.	s	R. A., % Avg.	s	E_t, 10^6 psi Avg.	s
70	131.0	1.9	142.9	1.5	12.2	0.4	42.4	2.5	15.3	0.1
400	96.5	2.4	116.7	1.6	13.8	0.6	48.7	2.4	14.0	0.6
600	85.7	2.2	108.3	1.7	13.1	0.6	48.2	3.1	13.9	0.6
800	81.5	2.1	104.6	1.8	14.3	1.2	50.3	3.5	13.0	0.4
1000	74.0	1.9	97.2	1.1	15.5	0.7	54.3	3.0	12.3	0.9

a Averages and standard deviations are based on 10 evaluations at each temperature.
b Heat treatment: 1650° F, 2 hr, A. C. + 930° F, 24 hr, A. C.
c Section size: 1/2 in. x 1-1/8 in.



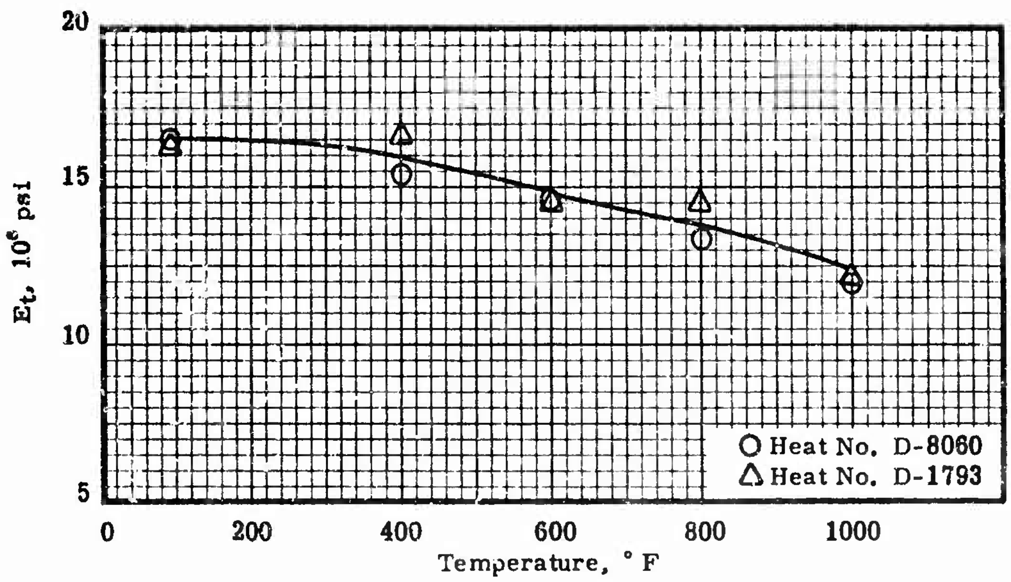


Figure 105. The 0.2%-Offset Yield Strength, Tensile Strength and the Modulus of Elasticity in Tension of Ti-5Al-5Sn-5Zr Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

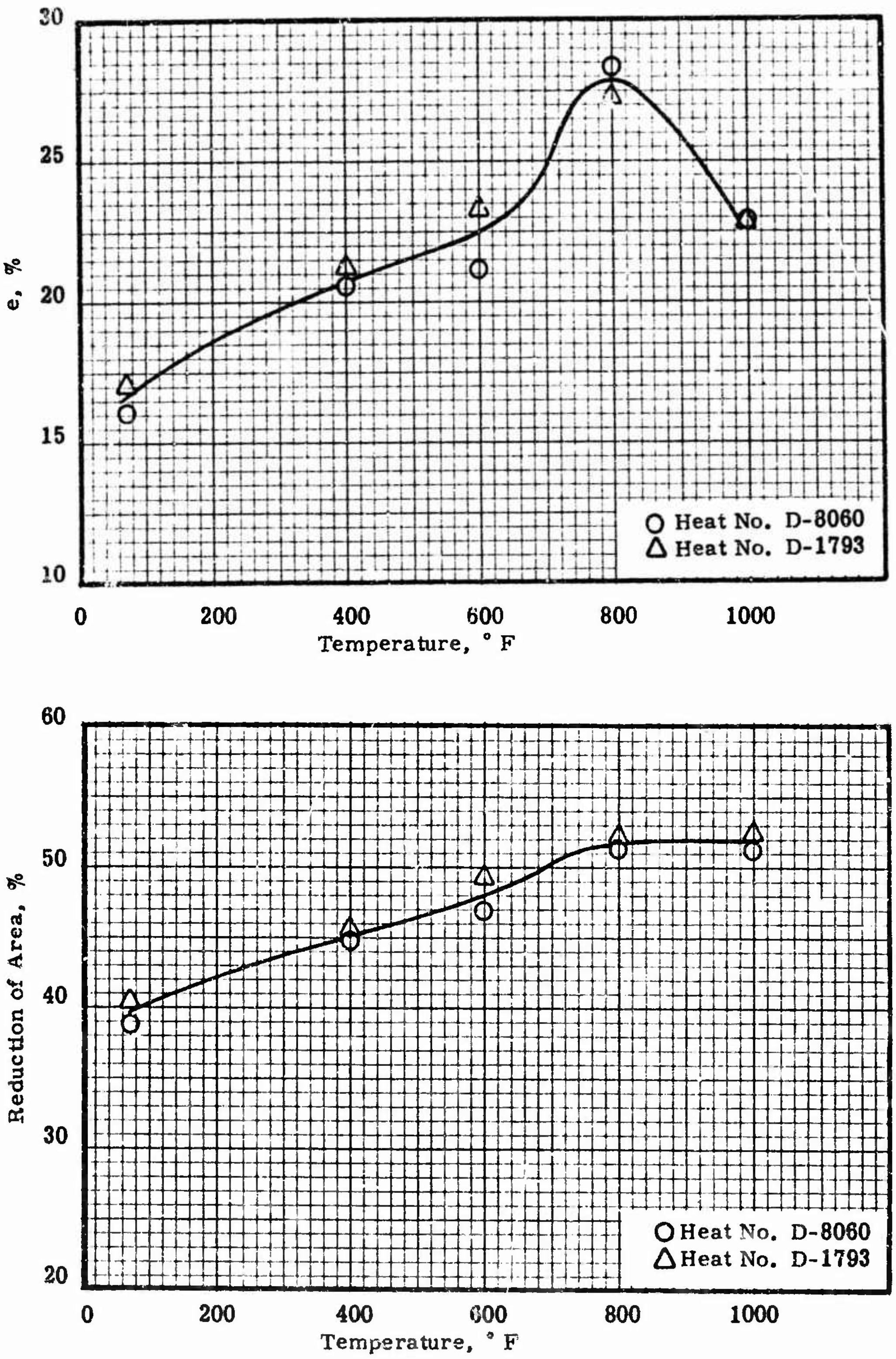


Figure 106. The Elongation and Reduction of Area of Ti-5Al-5Sn-5Zr Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

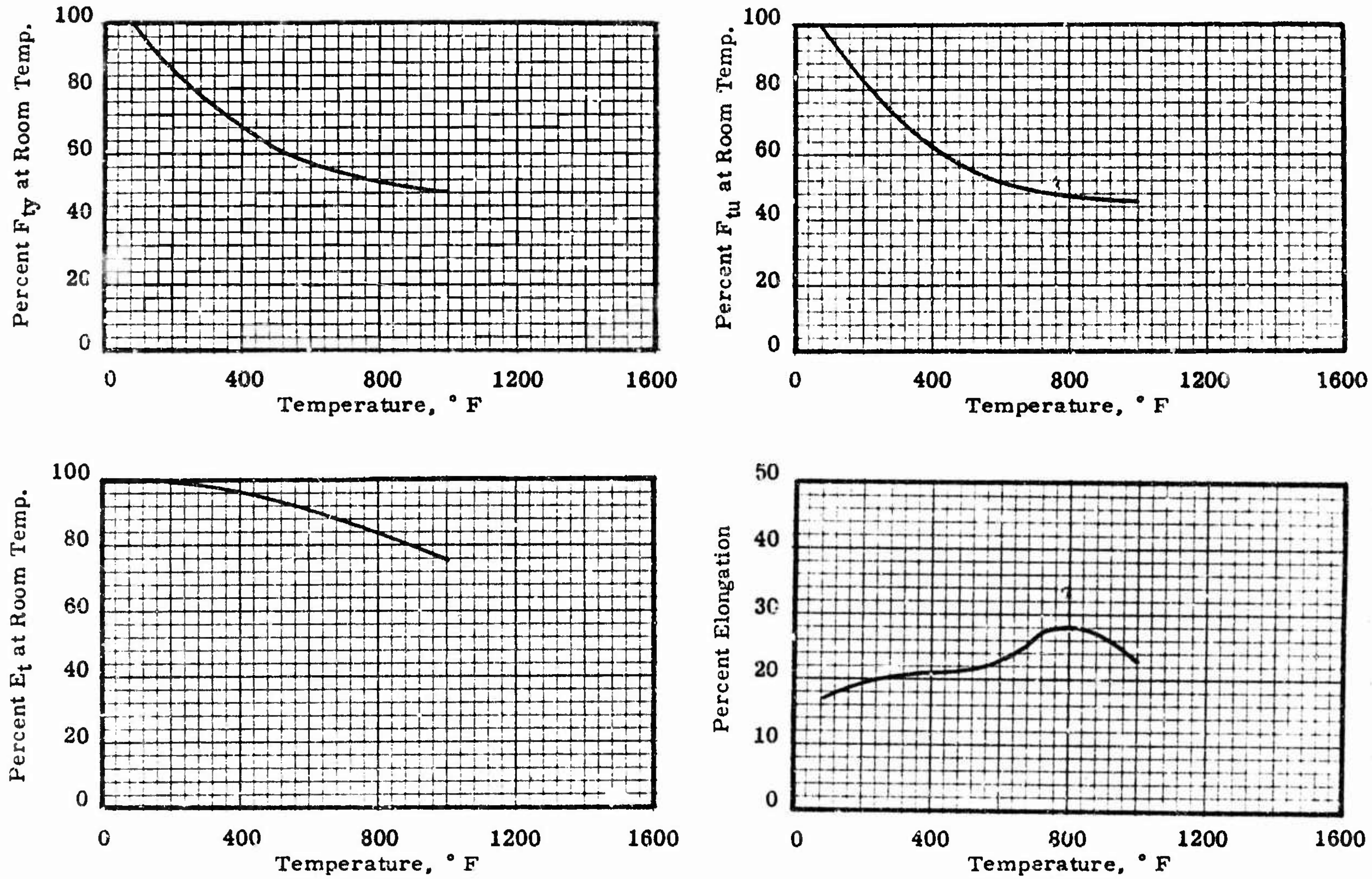


Figure 107. The Effect of Temperature on the Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

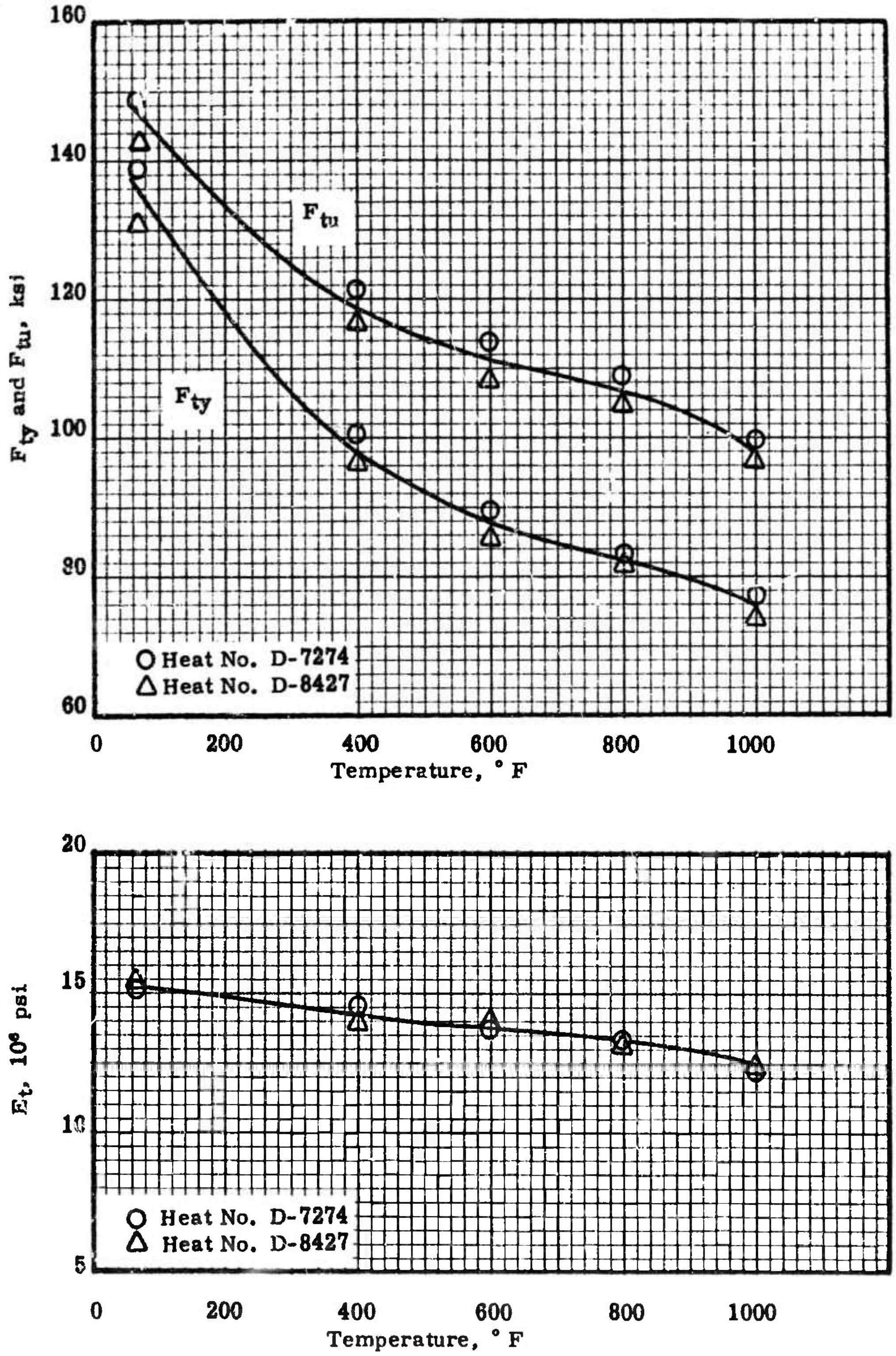


Figure 108. The 0.2%-Offset Yield Strength, Tensile Strength and the Modulus of Elasticity in Tension of Ti-679 Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930 F, 24 hr, A.C.

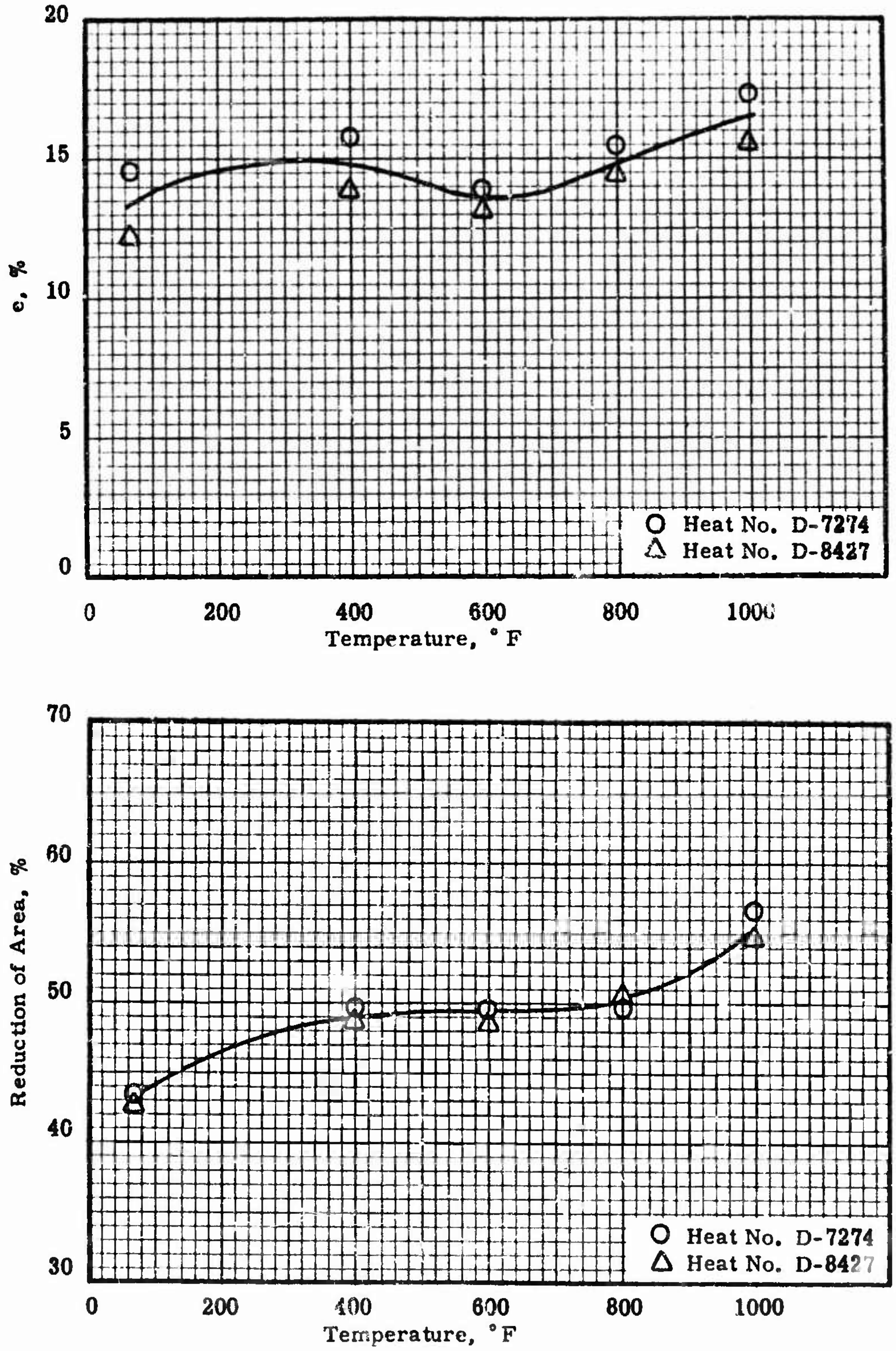


Figure 109. The Elongation and Reduction of Area of Ti-679 Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C., 930° F, 24 hr, A.C.

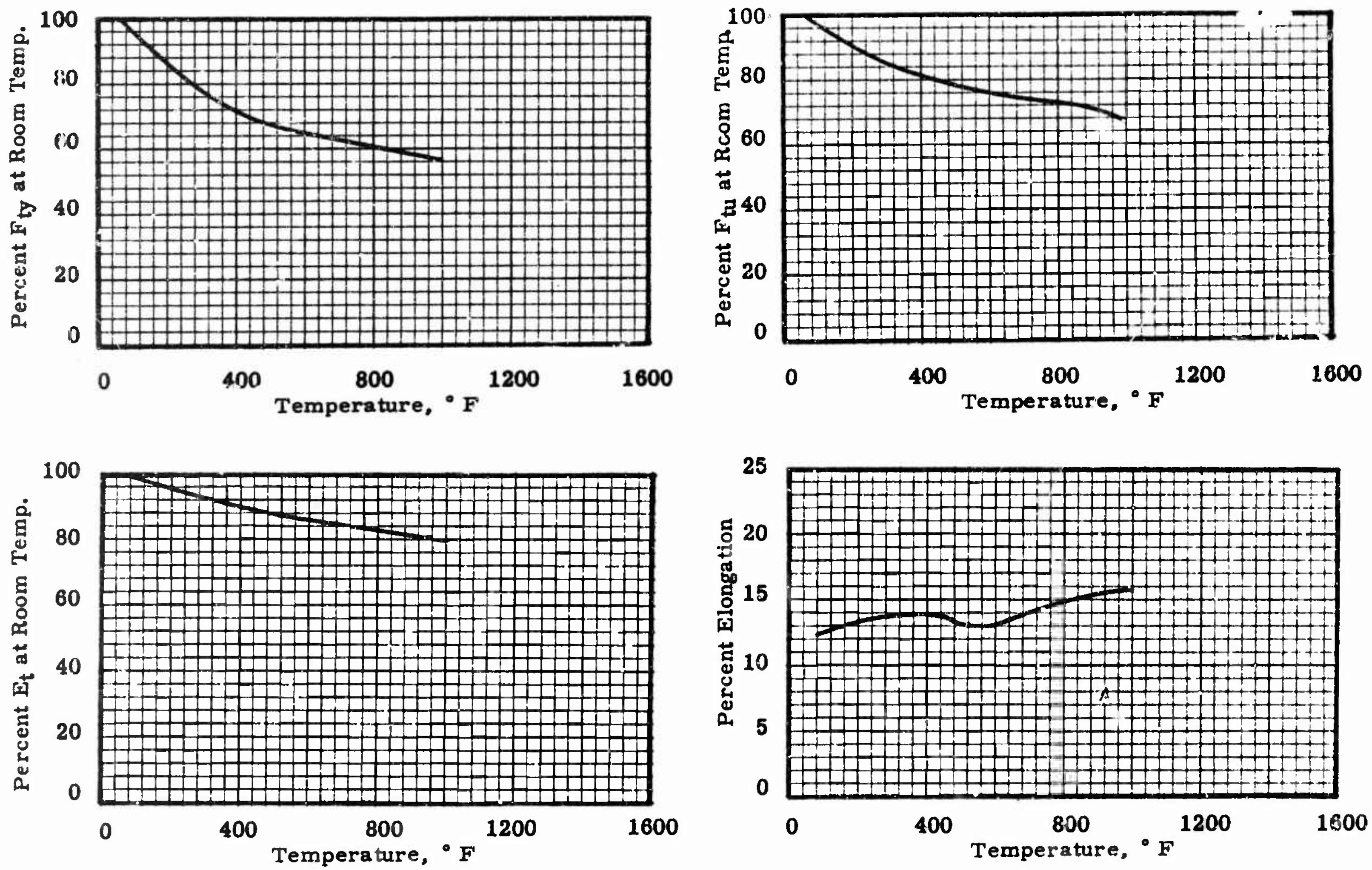


Figure 110. The Effect of Temperature on the Tensile Properties of Ti-679 Alloy Bar

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

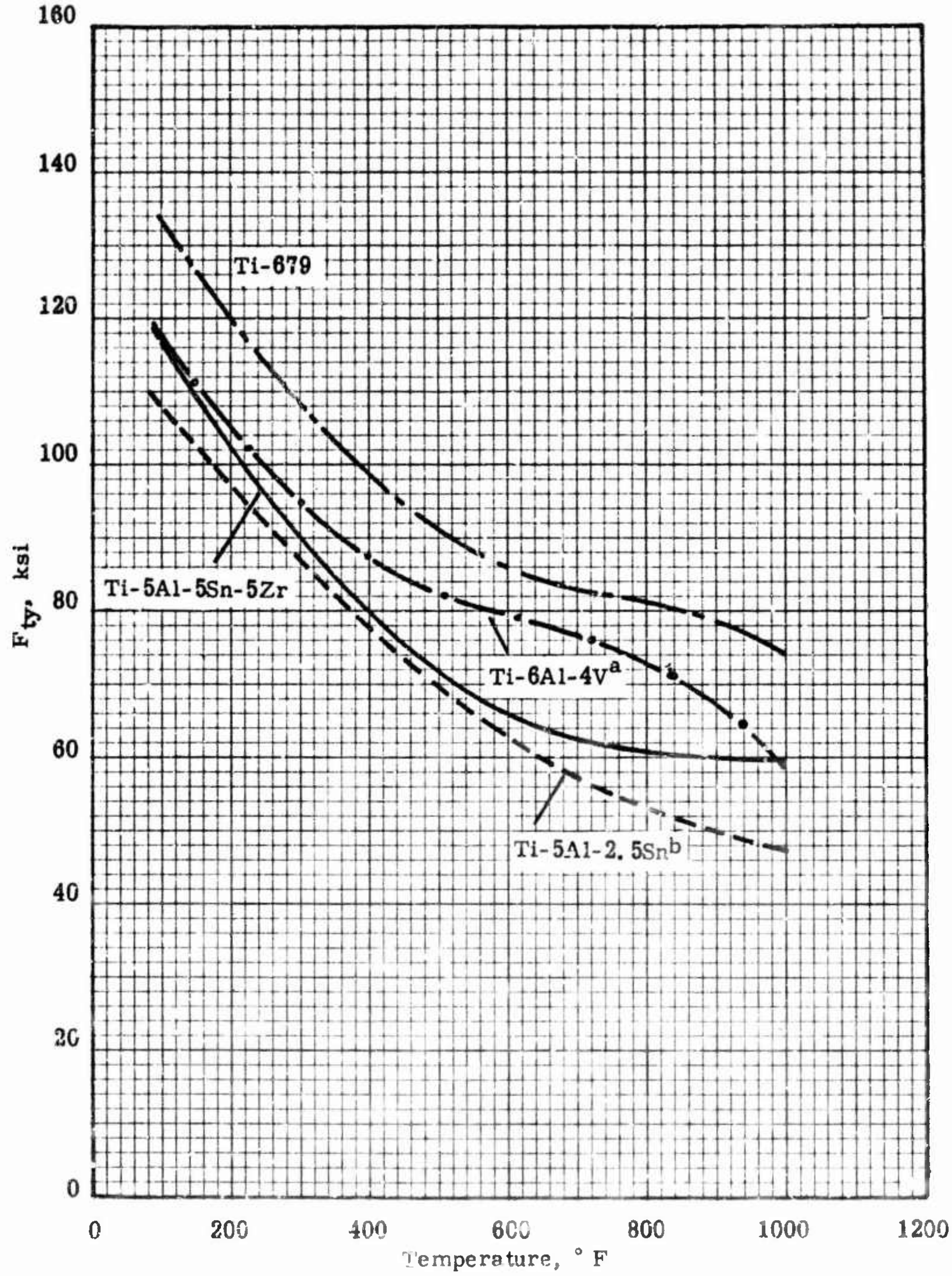


Figure 111. Comparison of the 0.2%-Offset Yield Strength of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys

Referenced data

a - MILHDBK 5, p 5.4.6.2.1 (b)
b - MILHDBK 5, p 5.3.1.2.1 (b)

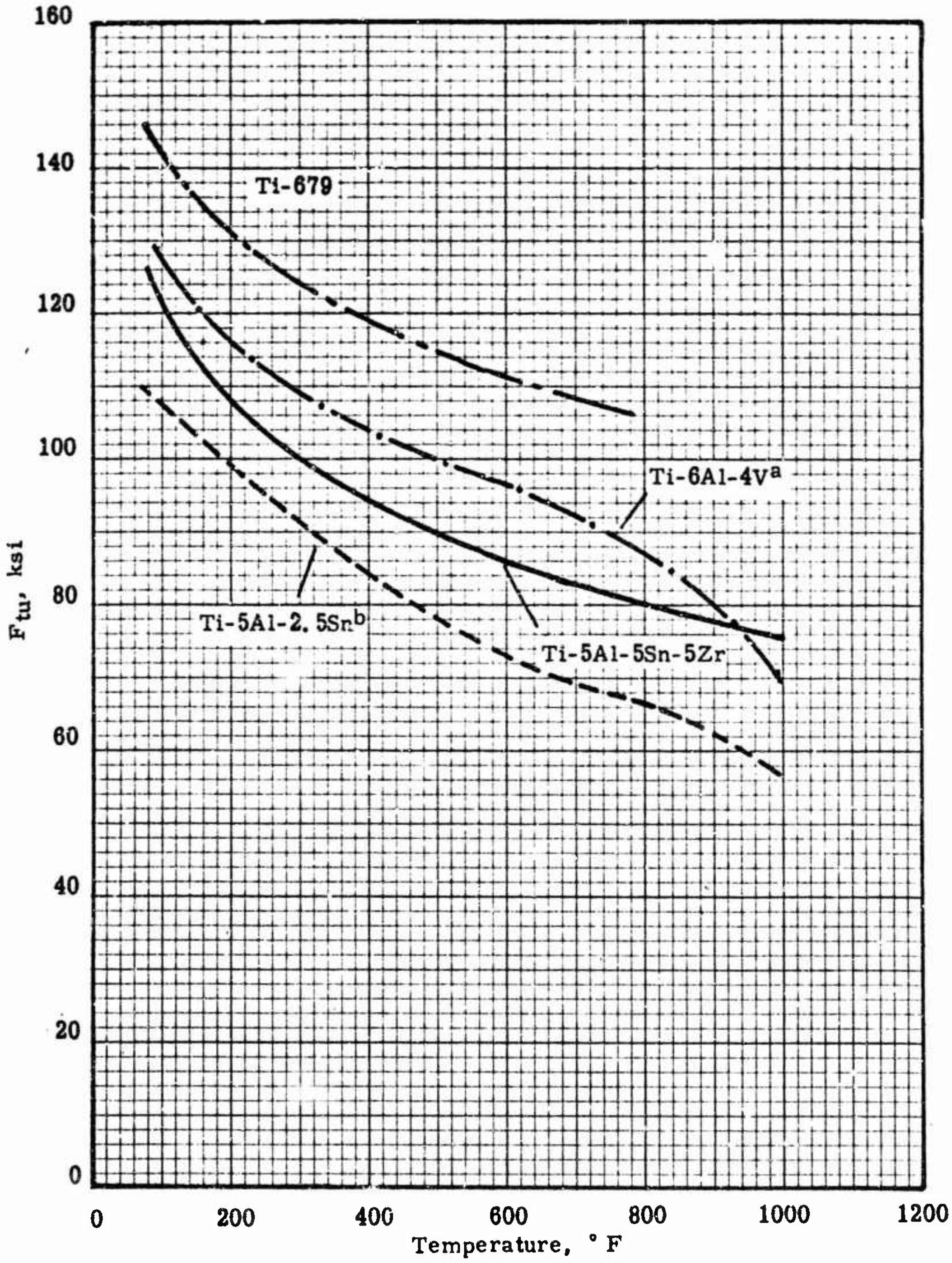


Figure 112. Comparison of the Ultimate Tensile Strength of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for other Titanium Alloys

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Referenced data
a - MILHDBK 5, p 5.4.6.2.1 (a)
b - MILHDBK 5, p 5.3.1.2.1 (a)

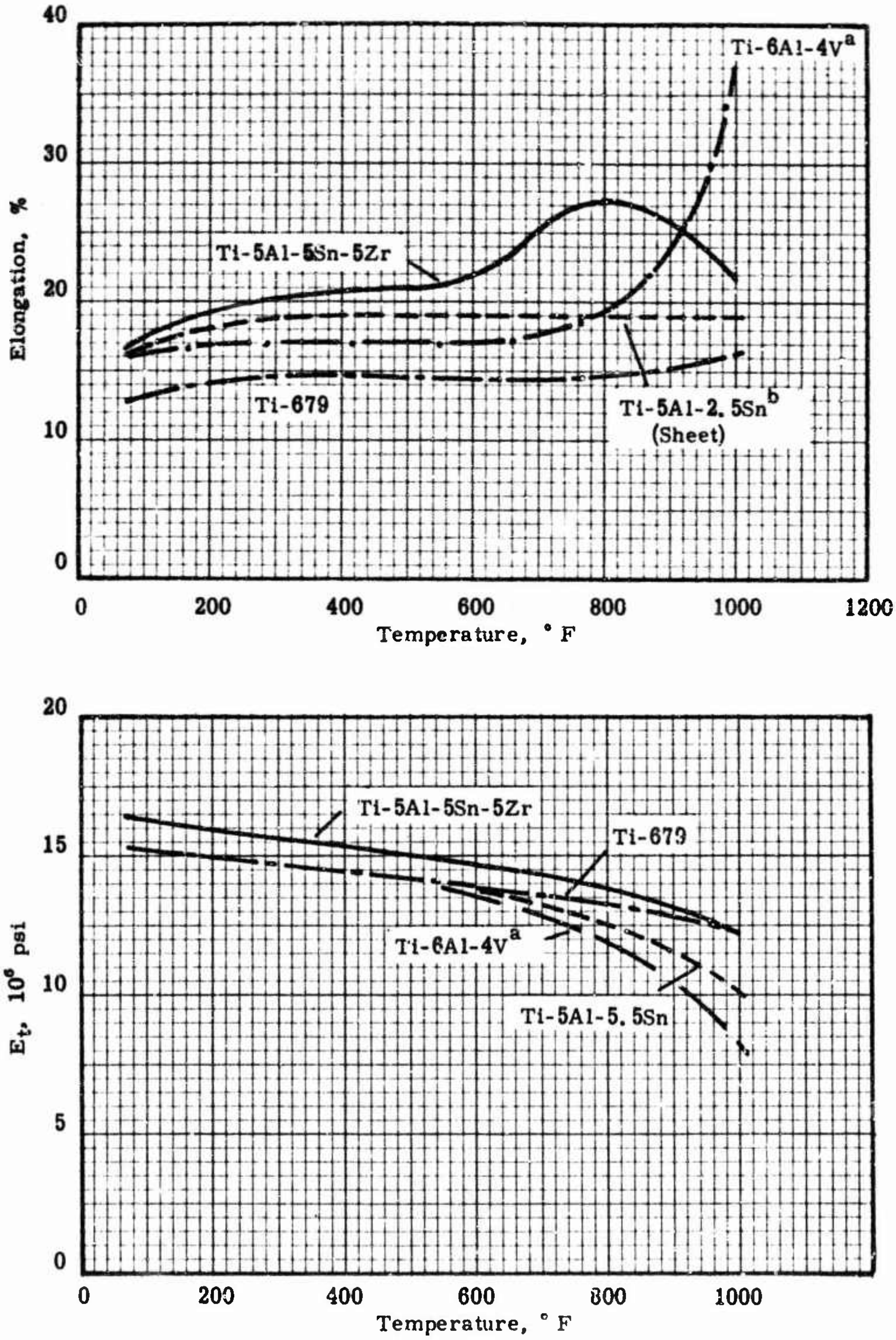

Figure 113. Comparison of Elongation and Modulus of Elasticity in Tension of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for other Titanium Alloys

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Referenced Data
a - MILHDBK 5, p 5.4.6.2.4
b - MILHDBK 5, p 5.3.1.2.4

Table 24

Precision Modulus of Elasticity of the Bar Alloys at Room Temperature[a, b, c]

Alloy	Modulus of Elasticity, 10^6 psi
Ti-5Al-5Sn-5Zr	16.563
Ti-679	15.806

a Section size: 1/2 in. x 1-1/8 in.

b Heat Nos.
Ti-5Al-5Sn-5Zr: D-8060
Ti-679: D-7274

c Heat treatment:
Ti-5Al-5Sn-5Zr: 1650° F, 2 hr, A.C.
Ti-679: 1650° F, 2 hr, A.C. +
930° F, 24 hr, A.C.

Table 25

Summary of Averaged Notched Tensile Strength of the Bar Alloys[a, b, c]

	Temperature, °F		
	70	400	800
Ti-5Al-5Sn-5Zr	199.0	140.6	115.6
Ti-679	218.7	175.6	164.8

a Section size: 1/2 in. x 1-1/8 in.

b Heat treatment:
Ti-5Al-5Sn-5Zr, 1650° F, 2 hr, A.C.
Ti-679, 1650° F, 2 hr, A.C. +
930° F, 24 hr, A.C.

c Notched 45°, 0.010 in. radius, 0.187 in. minimum diameter to produce K_t = 3.

Table 26

Summary of Averages and Standard Deviations for the Compression Properties at Different Temperatures of the Ti-5Al-5Sn-5Zr and Ti-679 Alloys in Bar Form[a]

Ti-5Al-5Sn-5Zr (Heat No. D-8060)

Temp, °F	F_{cy}, ksi		E_c, 10^6 psi	
	Avg.	s	Avg.	s
70	126.9	3.1	15.4	0.3
400	86.9	2.5	14.2	0.1
600	73.5	2.8	13.3	0.2
800	64.8	3.0	12.6	0.2
1000	64.3	2.5	11.8	0.2

Heat treatment: 1650° F, 2 hr, A.C.

Ti-679 (Heat No. D-7274)

Temp, °F	F_{cy}, ksi		E_c, 10^6 psi	
	Avg.	s	Avg.	s
70	140.2	1.7	14.5	0.2
400	104.4	3.8	13.8	0.2
600	93.3	1.0	12.9	0.2
800	87.0	1.5	12.0	0.1
1000	80.2	1.1	11.5	0.2

Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

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[a] Section size: 1/2 in. x 1-1/8 in.

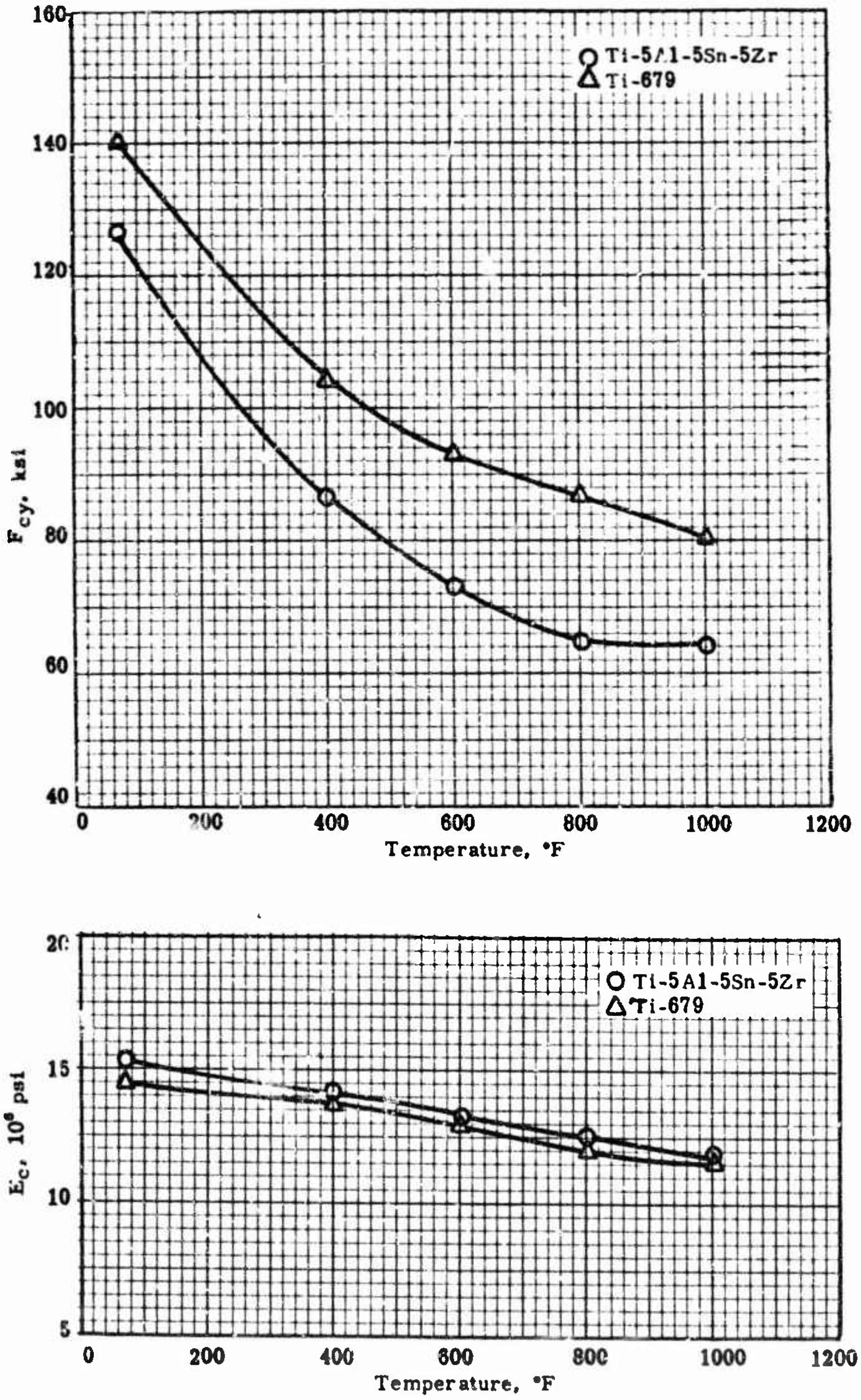
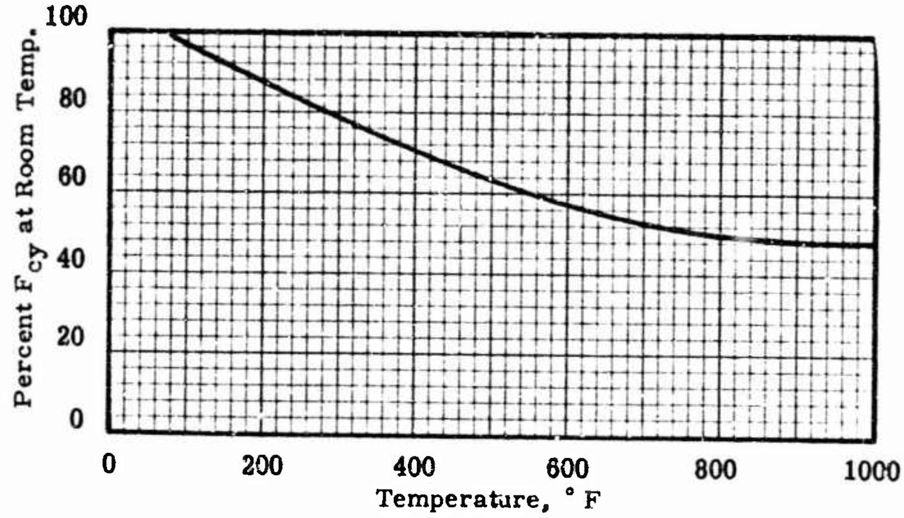


Figure 114. The 0.2%-Offset Yield Strength and Modulus of Elasticity in Compression of Ti-5Al-5Sn-5Zr and Ti-679 Alloys in Bar Form at Different Temperatures.

	Ti-5Al-5Sn-5Zr	Ti-679
Heat No.	D-8060	D-7274
Heat treatment:	1650° F, 2 hr, A.C.	1650°F, 2 hr, A.C. + 930°F, 24hr, A.C.
Section size:	1-1/8 in. x 1/2 in.	1-1/8 in. x 1/2 in.



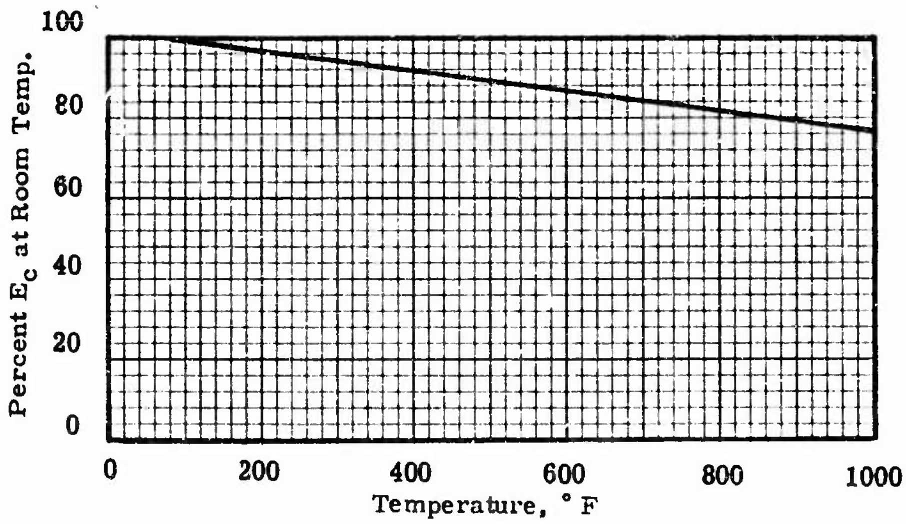
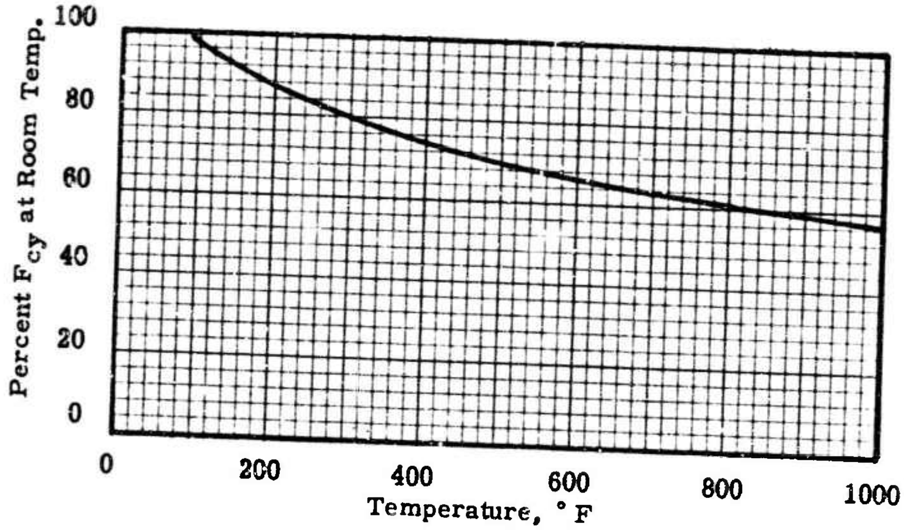


Figure 115. Effect of Temperature on the Compressive Properties of Ti-5Al-5Sn-5Zr Alloy Bar

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C.



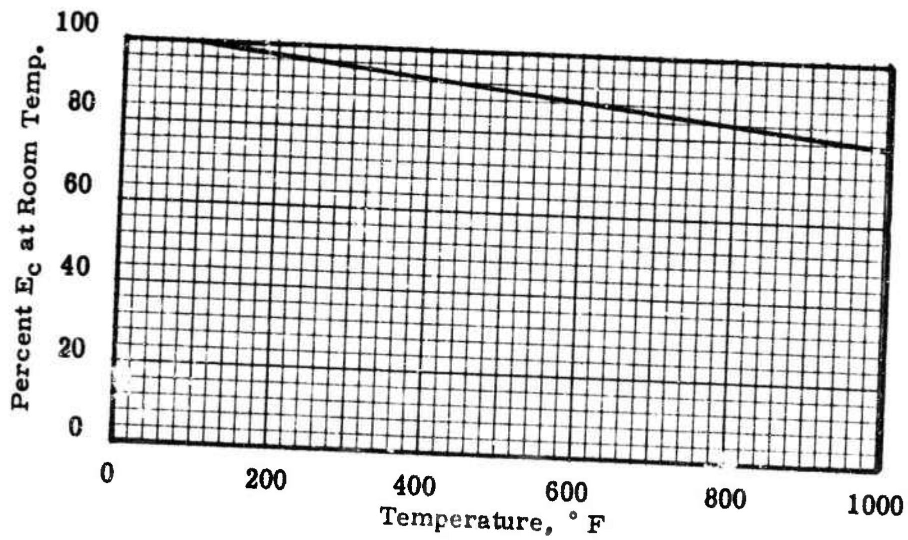


Figure 116. Effect of Temperature on the Compressive Properties of Ti-679 Alloy Bar

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

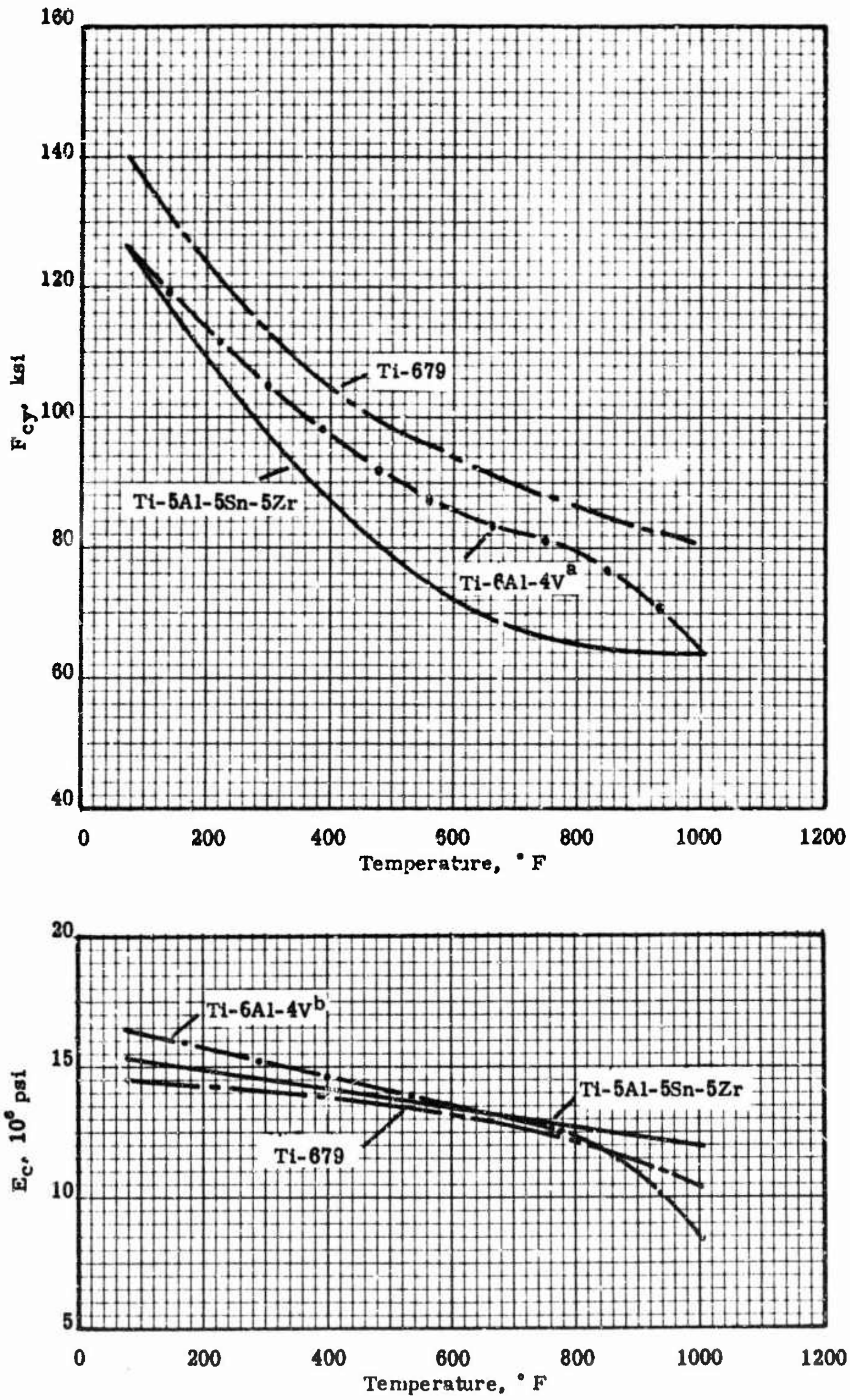


Figure 117. Comparison of the Compressive Properties of Titanium Alloy Bar Evaluated in this Program with Data from the Literatur for Other Titanium Alloys.

Referenced data
a - MILHDBK 5, p 5.4.6.2.2. (a)
b - MILHDBK 5, p 5.4.6.2.4

Shear

Data on the shear strength of the Ti-679 and Ti-5Al-5Sn-5Zr bar alloys are given in tables and figures as shown below:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	118, 120, 121	27, 77
Ti-679	119, 120, 121	27, 78

Tables with numbers underlined are in Appendix I

The ultimate shear strengths of the bar alloys were about 0.7 to 0.8 of their respective tensile strengths at room and elevated temperatures.

Thermal Exposure

Data for tensile and hardness tests subsequent to thermal exposure are given in tables and figures as shown below:

Alloy	Figure	Tables
Ti-5Al-5Sn-5Zr	122	79, 80
Ti-679	123	79, 81

Tables with numbers underlined are in Appendix I

No significant change in tensile properties was observed, either in tests at room temperature or at the exposure temperature, which indicates that the tensile properties of the bar alloys were not adversely affected by thermal exposure.

Table 27

Summary of Averages and Standard Deviations for the Ultimate Shear Strength at Different Temperatures of Two Titanium Alloys, Bar Form[a,b]

Temp. °F	Ti-5Al-5Sn-5Zr F_{su}, ksi Avg.	Ti-5Al-5Sn-5Zr F_{su}, ksi s	Ti-679 F_{su}, ksi Avg.	Ti-679 F_{su}, ksi s
70	102.9	3.9	106.5	3.8
400	76.7	1.7	85.6	3.8
600	70.2	2.6	80.8	1.5
800	65.3	1.3	77.4	1.6
1000	61.5	0.3	72.3	2.6

a Section size: 1-1/8 in. x 1/2 in.

b Heat treatments:
Ti-5Al-5Sn-5Zr, 1650° F, 2 hr, A.C.
Ti-679, 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

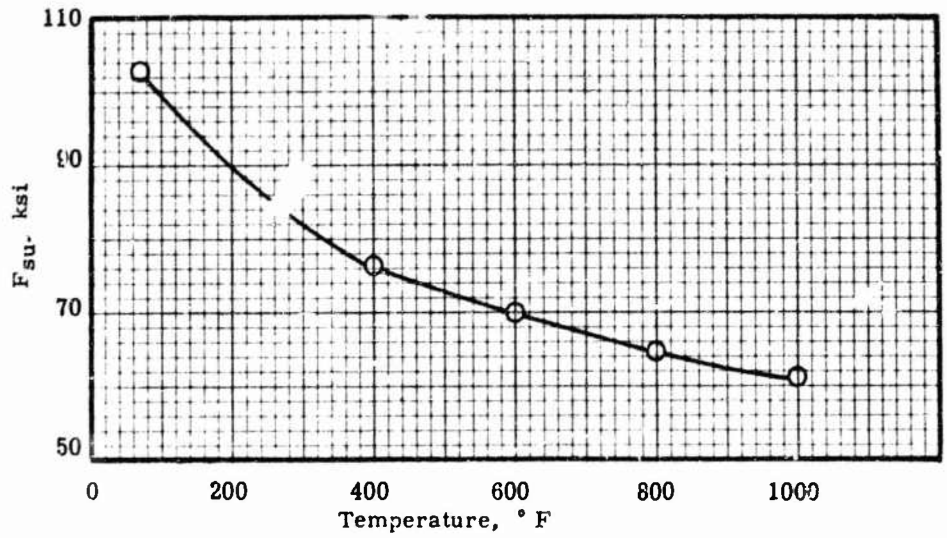


Figure 118. The Ultimate Shear Strength of Ti-5Al-5Sn-5Zr Alloy Bar at Different Temperatures.

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C.

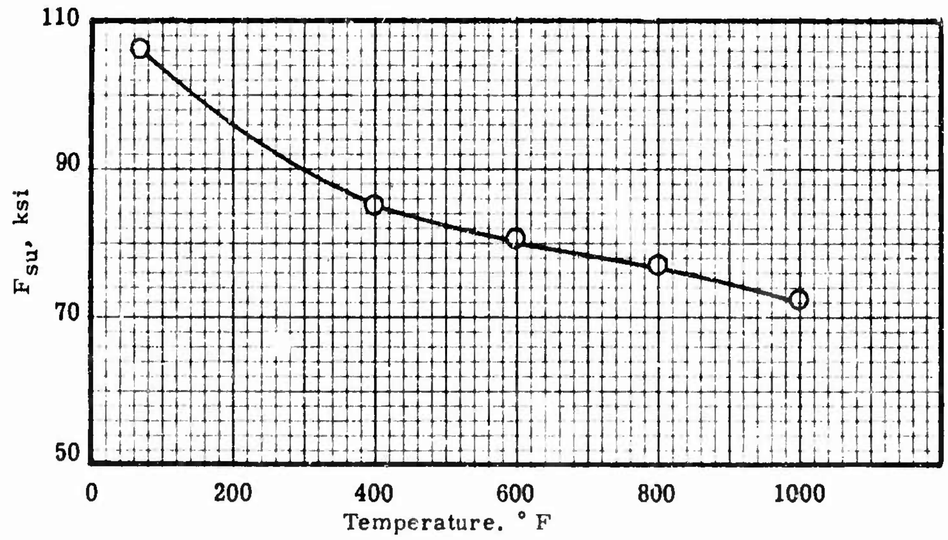
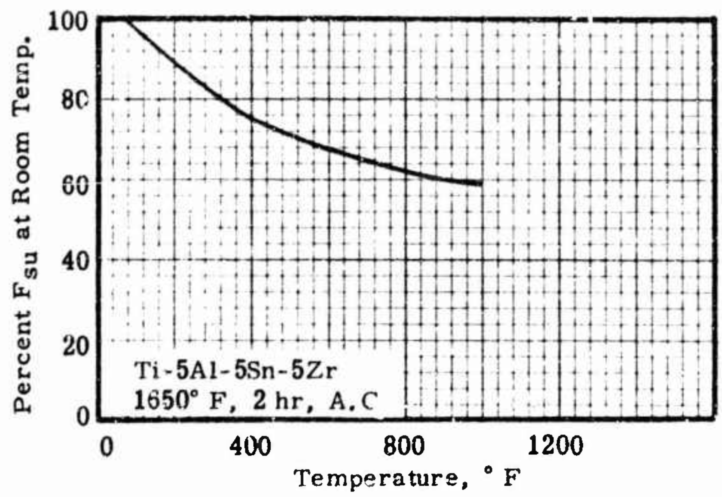


Figure 119. The Ultimate Shear Strength of Ti-679 Alloy Bar at Different Temperatures.

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.



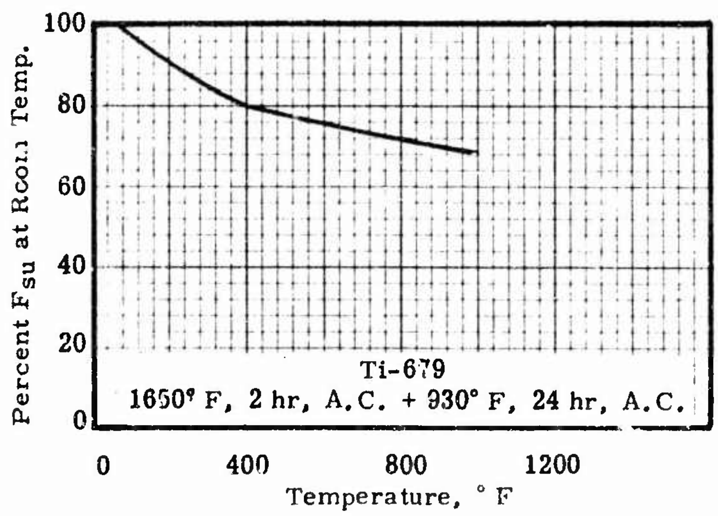


Figure 120. The Effect of Temperature on the Ultimate Shear Strength of Two Titanium Alloys

Section size: 1/2 in. x 1-1/8 in.
Heat treatment: As shown for each alloy.

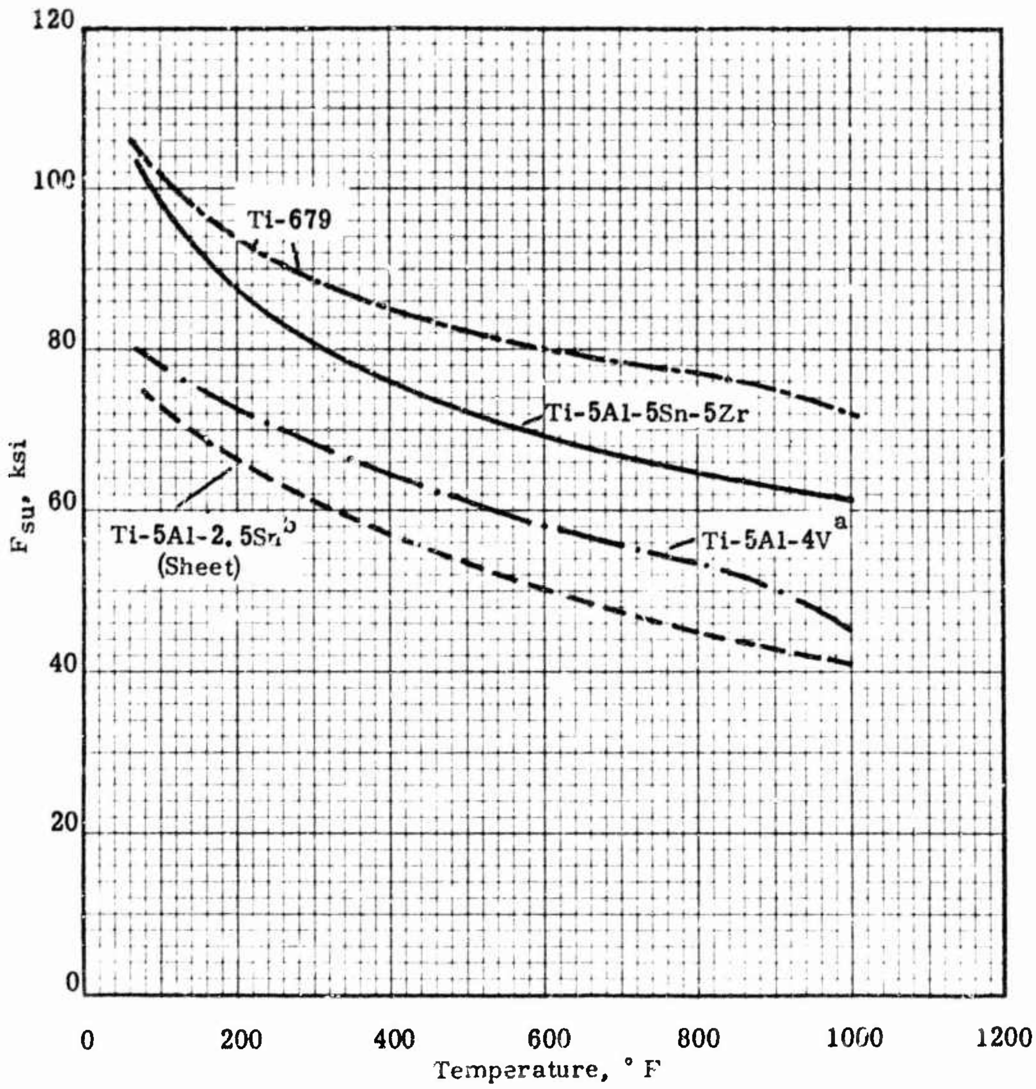


Figure 121. Comparison of Ultimate Shear Strength of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys.

Referenced Data
a MIL HDBK 5, p 5.4.6.2.2 (a)
b MIL HDBK 5, p 5.3.1.2.2 (a)

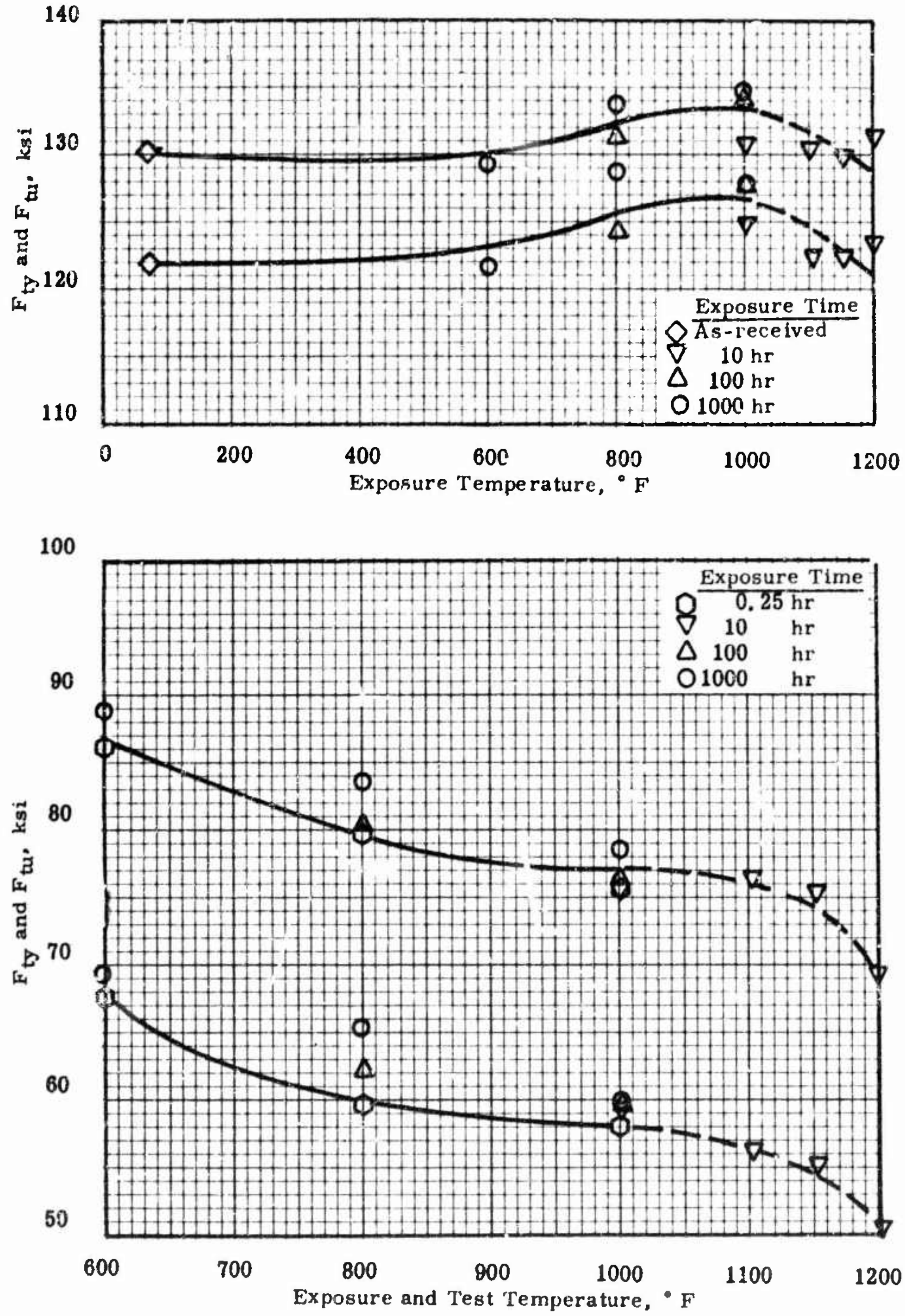
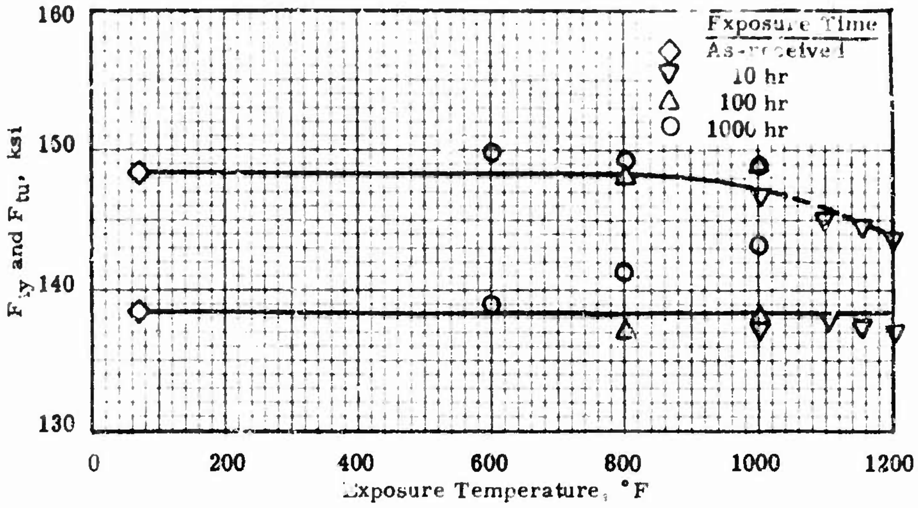


Figure 122. Effect of Thermal Exposure on the Tensile-Strength Properties of Ti-5Al-5Sn-5Zr Alloy Bar at Room Temperature (above) and at the Exposure Temperature (below).

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 h, A C.



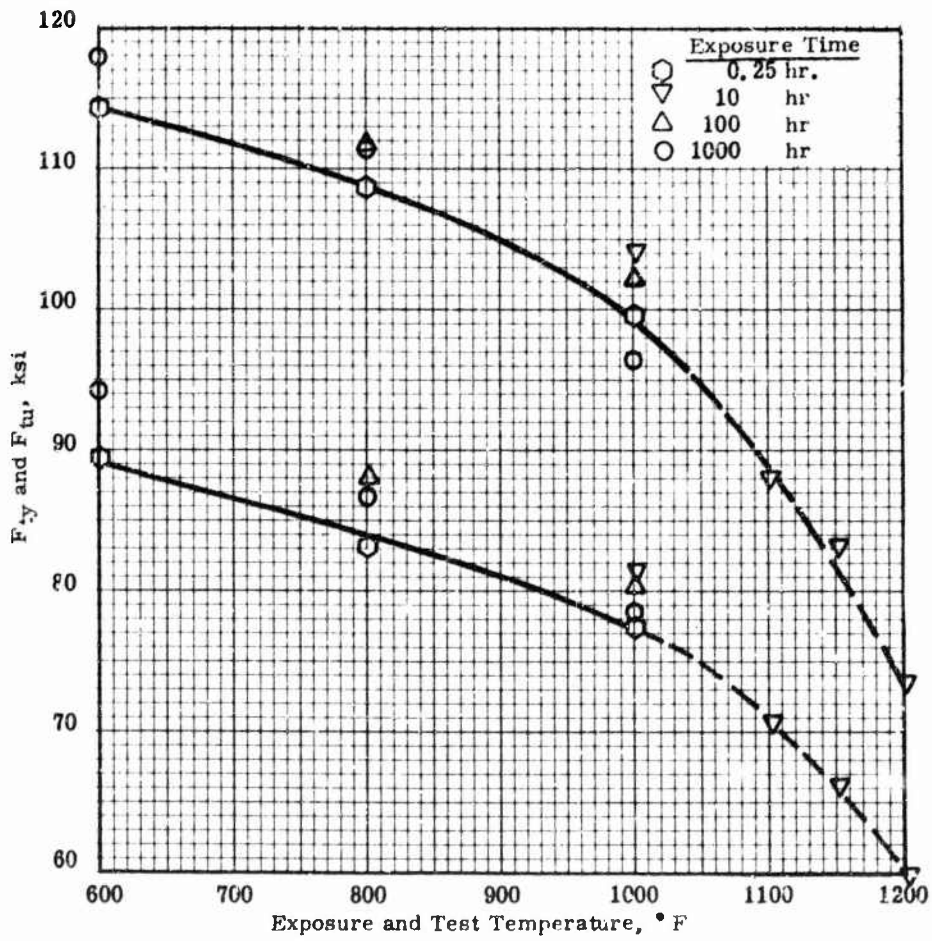


Figure 123. Effect of Thermal Exposure on the Tensile-Strength Properties of Ti-679 Alloy Bar at Room Temperature (above) and at the Exposure Temperature (below)

Heat No. D-7274
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C., 930° F, A.C.

Creep

The results of creep tests on the bar alloys are given in the tables and figures as shown below:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	124, 125, 126, 127, 132, 133	82
Ti-679	128, 129, 130, 131, 132, 133	83

Tables shown are in Appendix I

Comparative creep data at the 0.1% and 0.5% deformation, in Figures 132 and 133 respectively, show that the creep strength of the Ti-679 alloy is superior to that of the Ti-5Al-5Sn-5Zr alloy at low parameter values, but the relative creep strength of the two alloys reversed for higher values of the time-temperature parameter. Both bar alloys evaluated in this program had higher creep strength than the comparative alloys for which data are shown in Figures 132 and 133.

Impact

Data for the impact tests on the two bar alloys are given in Tables 28 and 29 and Figure 134. The results of individual tests are shown in Tables 84 and 85 in Appendix I. The impact strength of the alloys was comparable at room temperature, but at elevated temperatures the Ti-5Al-5Sn-5Zr had higher impact strength than the Ti-679 alloy.

Fatigue

Results of the fatigue tests on unnotched and notched specimens of the two bar alloys are shown in the following tables and figures:

Alloy	Figures	Tables
Ti-5Al-5Sn-5Zr	135, 136, 137, 138, 139	86
Ti-679	140, 141, 142, 143, 144	87

Tables are in Appendix I

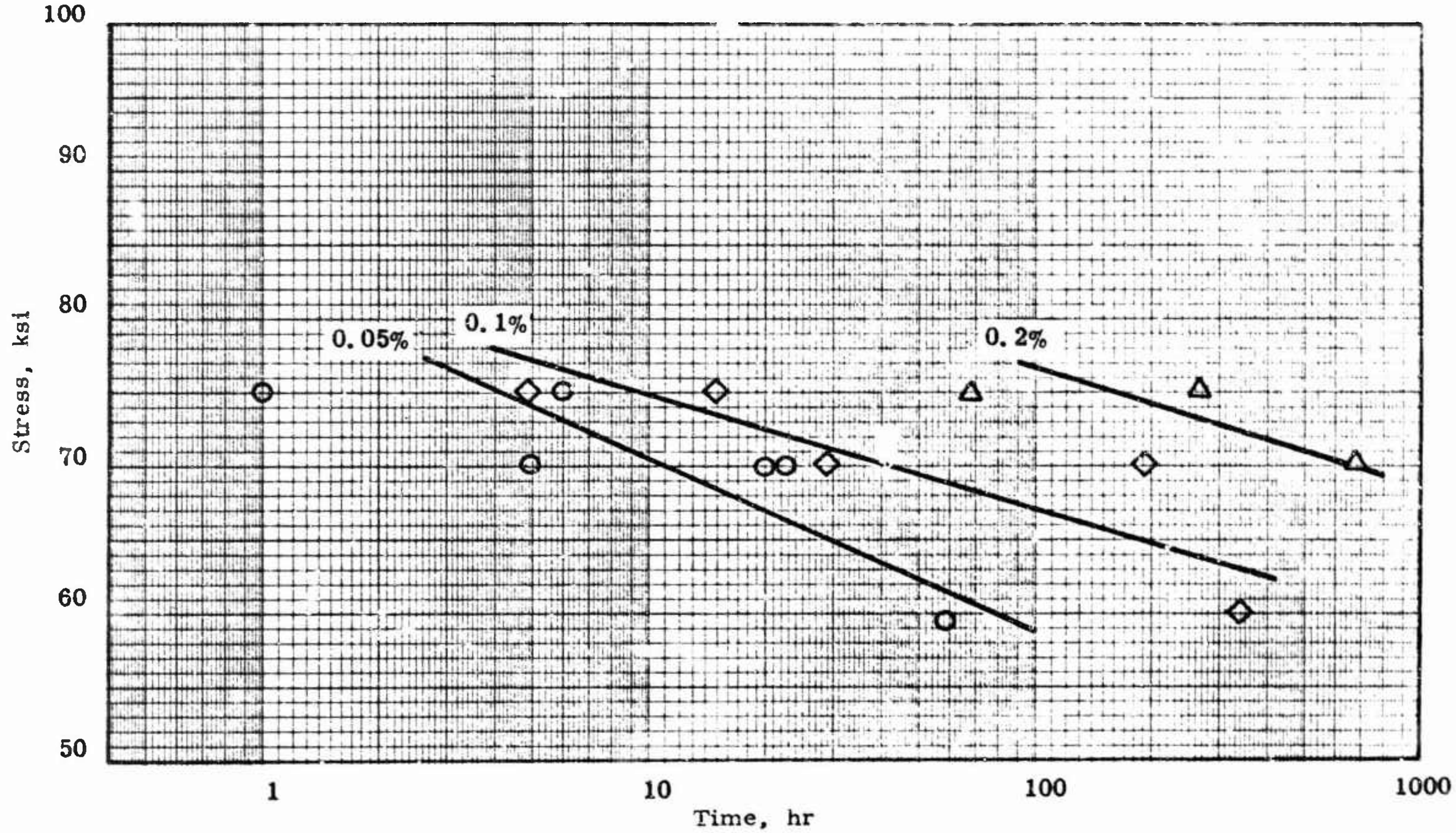


Figure 124. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Bar at 800° F.

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

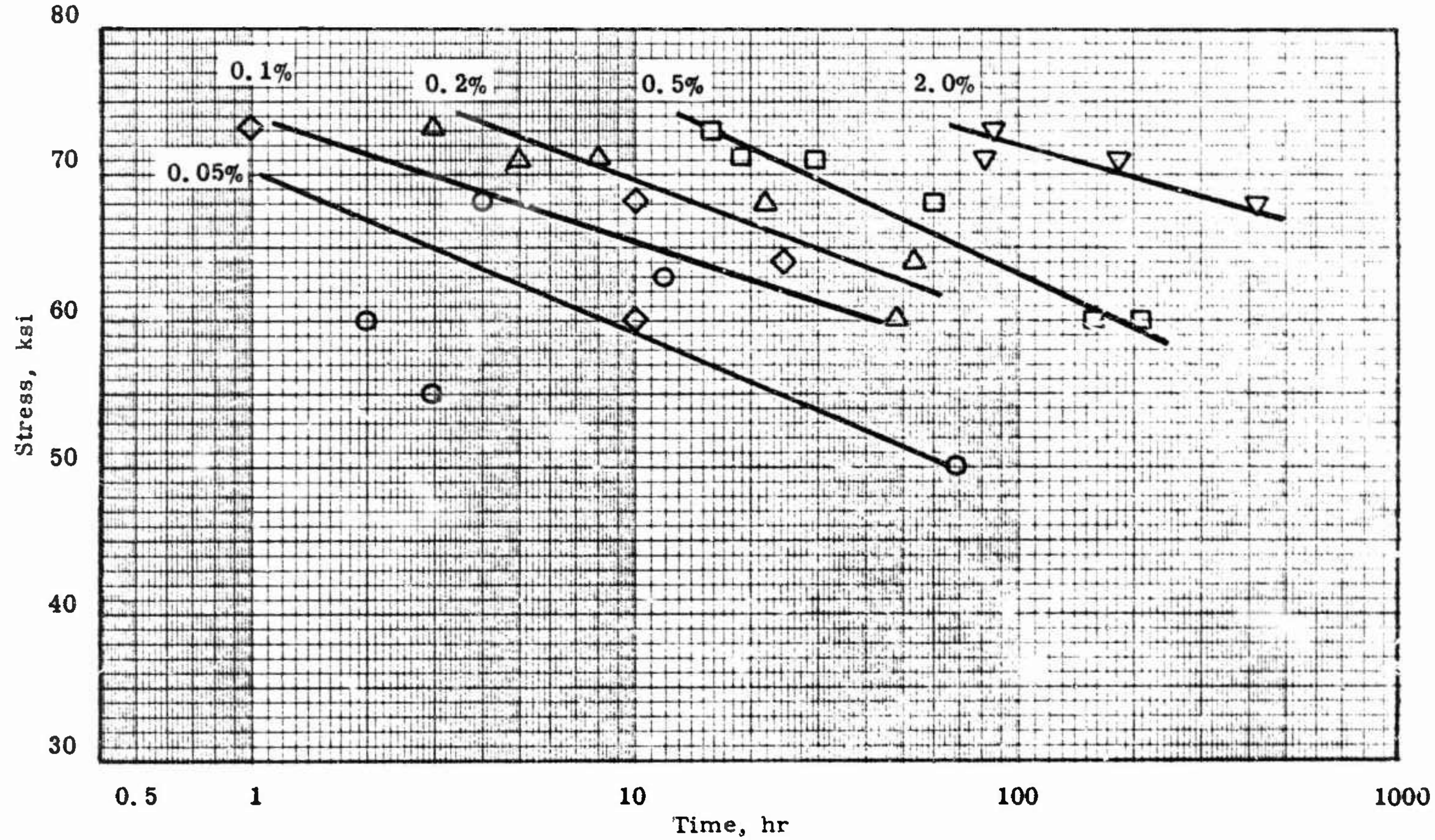


Figure 125. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Bar at 900° F.

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

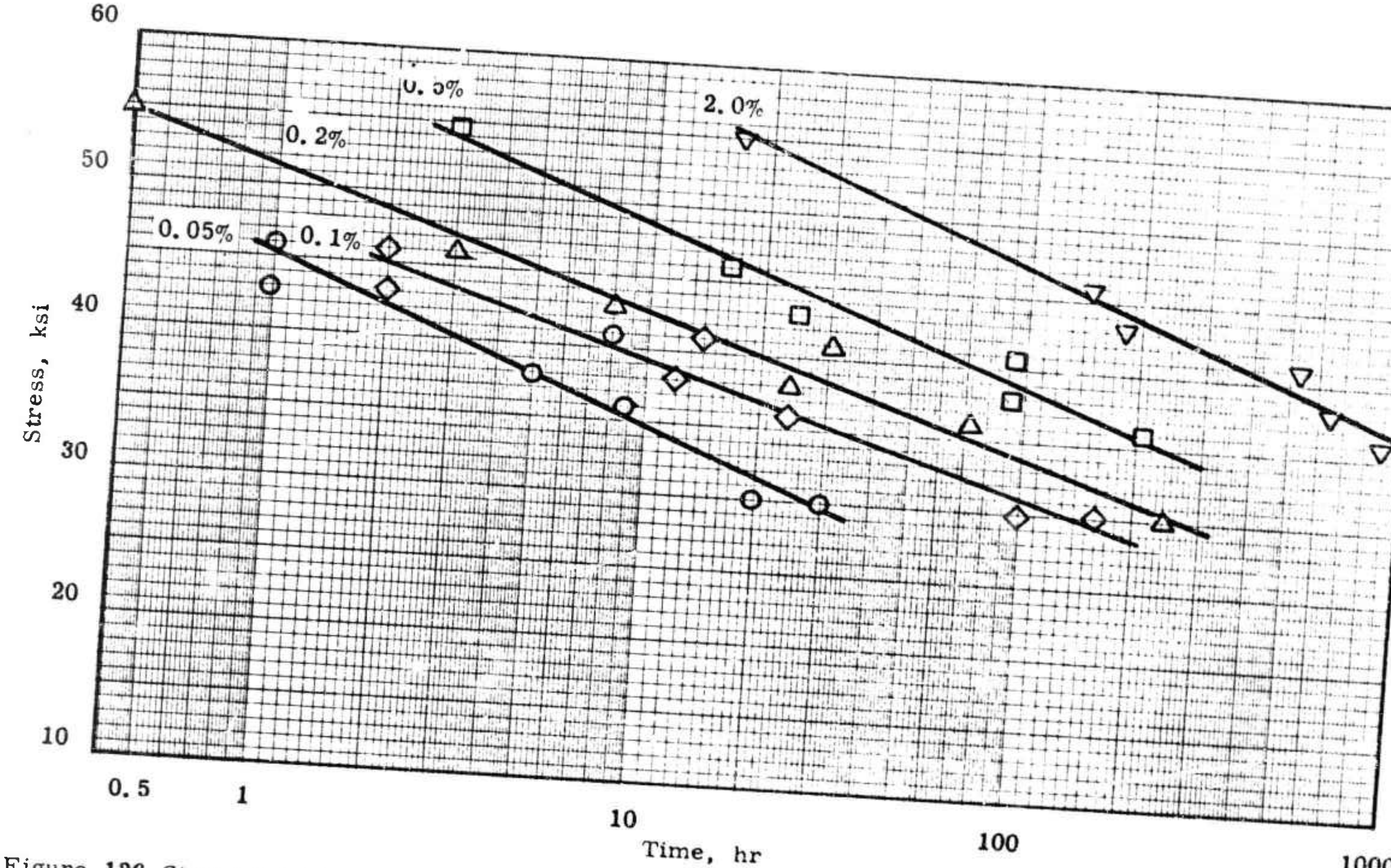


Figure 126. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-5Al-5Sn-5Zr Alloy Bar at 1000° F.

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

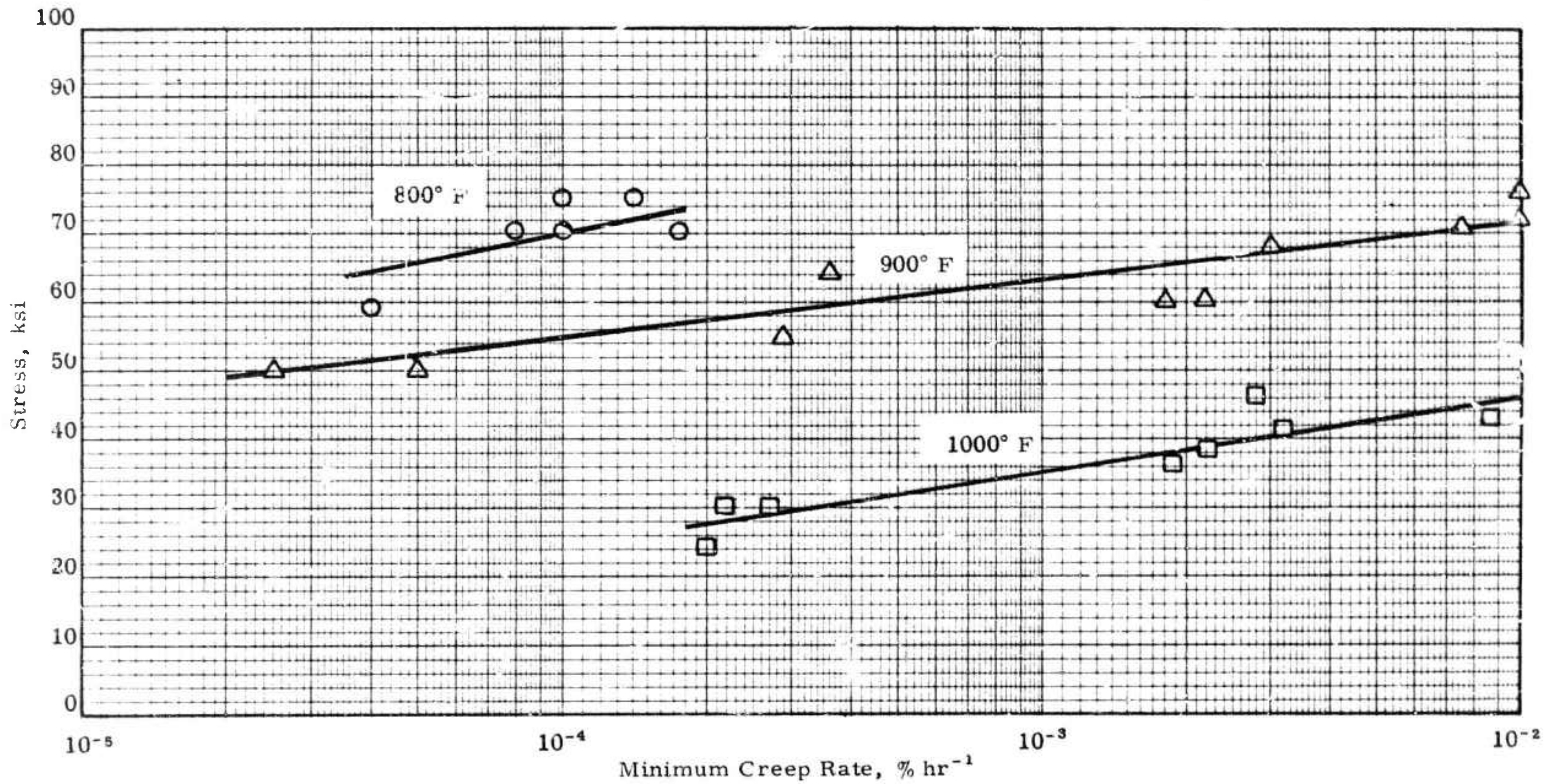


Figure 127. Minimum Creep Rate of Ti-5Al-5Sn-5Zr Alloy Bar at Different Temperatures.

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

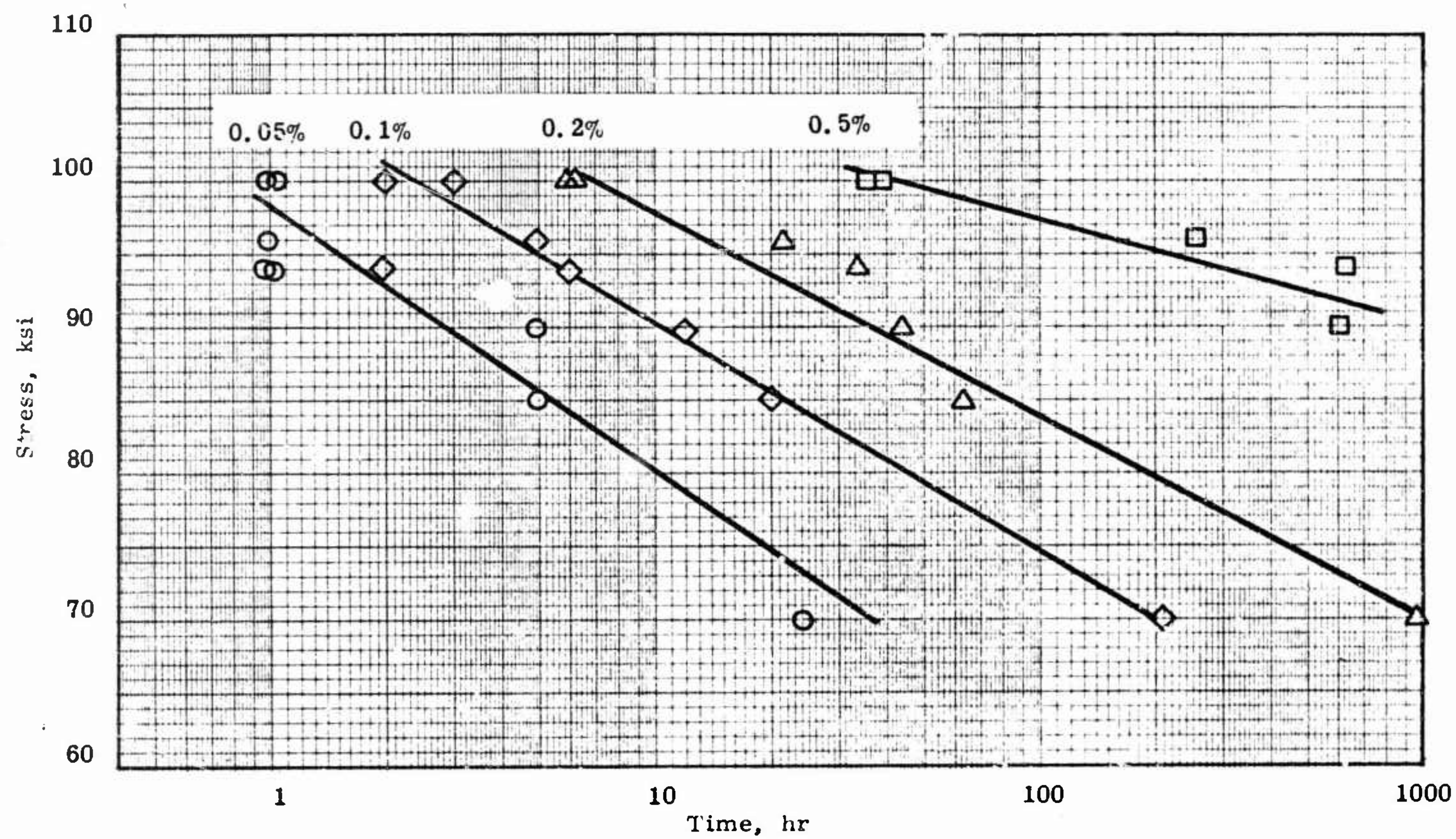


Figure 128. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-679 Alloy Bar at 800° F.

Heat No. D-7274
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

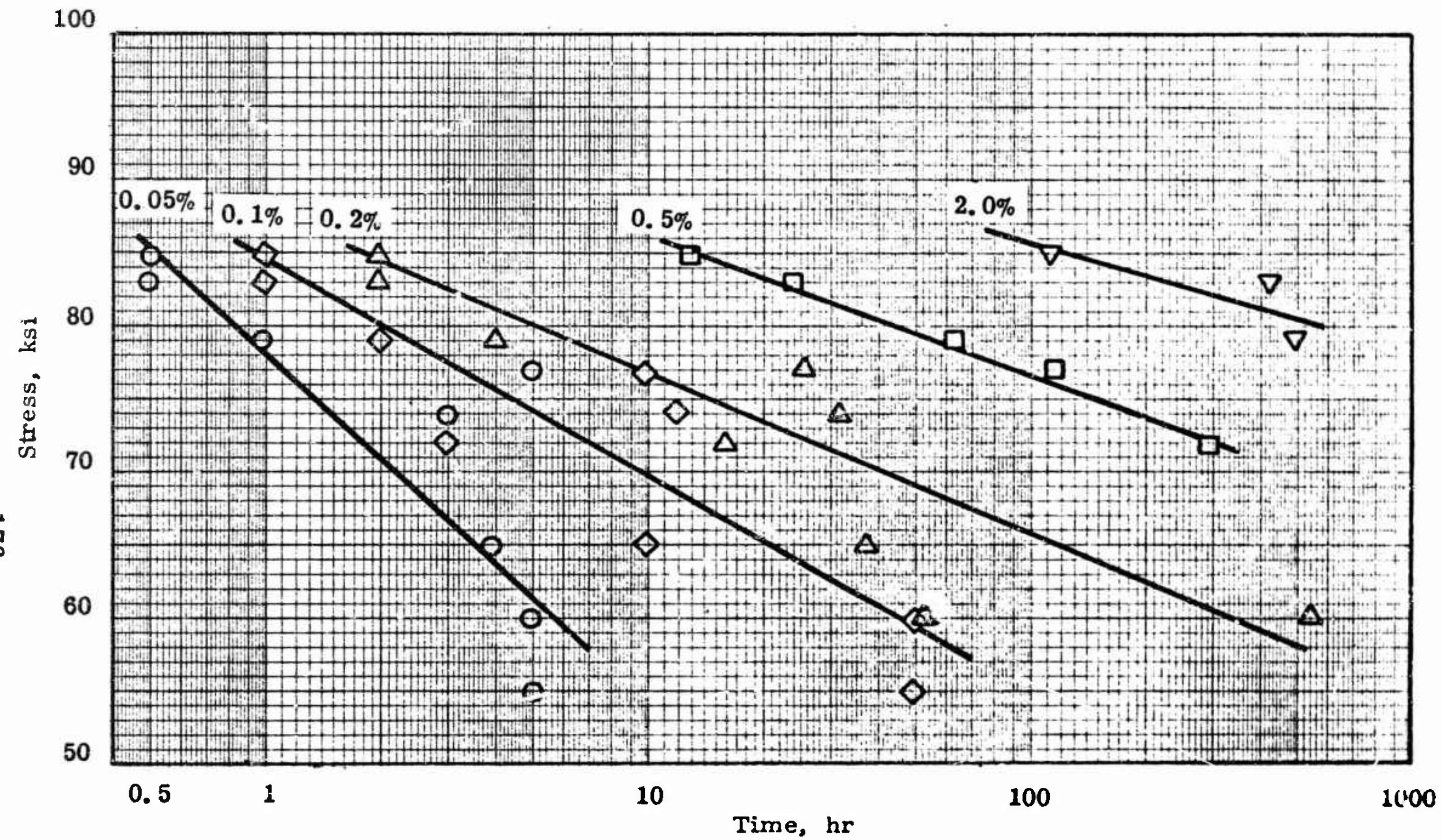


Figure 129. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-679 Alloy at 900° F.

Heat No. D7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

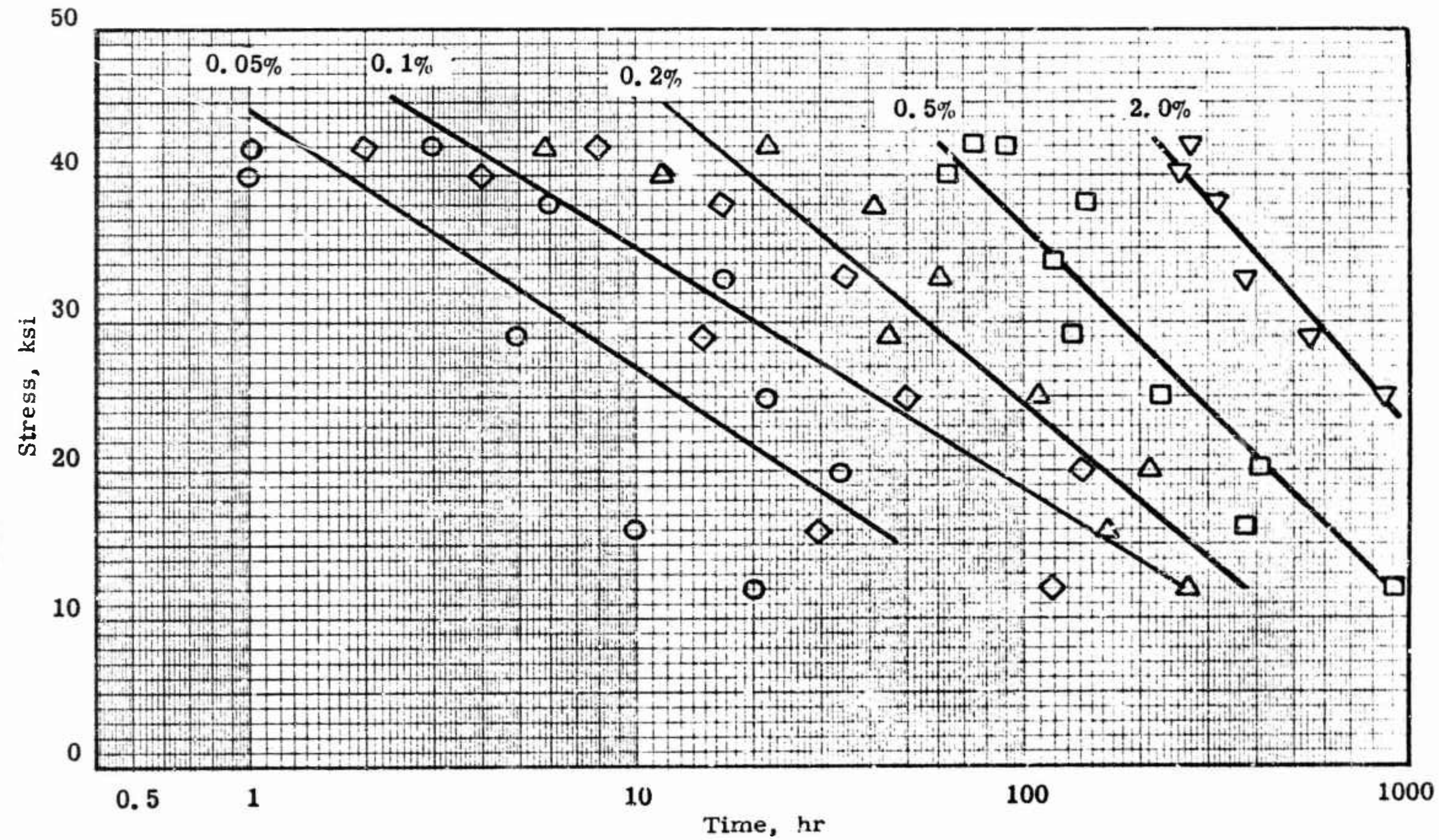


Figure 130. Stress for Different Amounts of Creep Deformation as a Function of Time for the Ti-679 Alloy Bar at 1000° F.

Heat No. D-7274
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

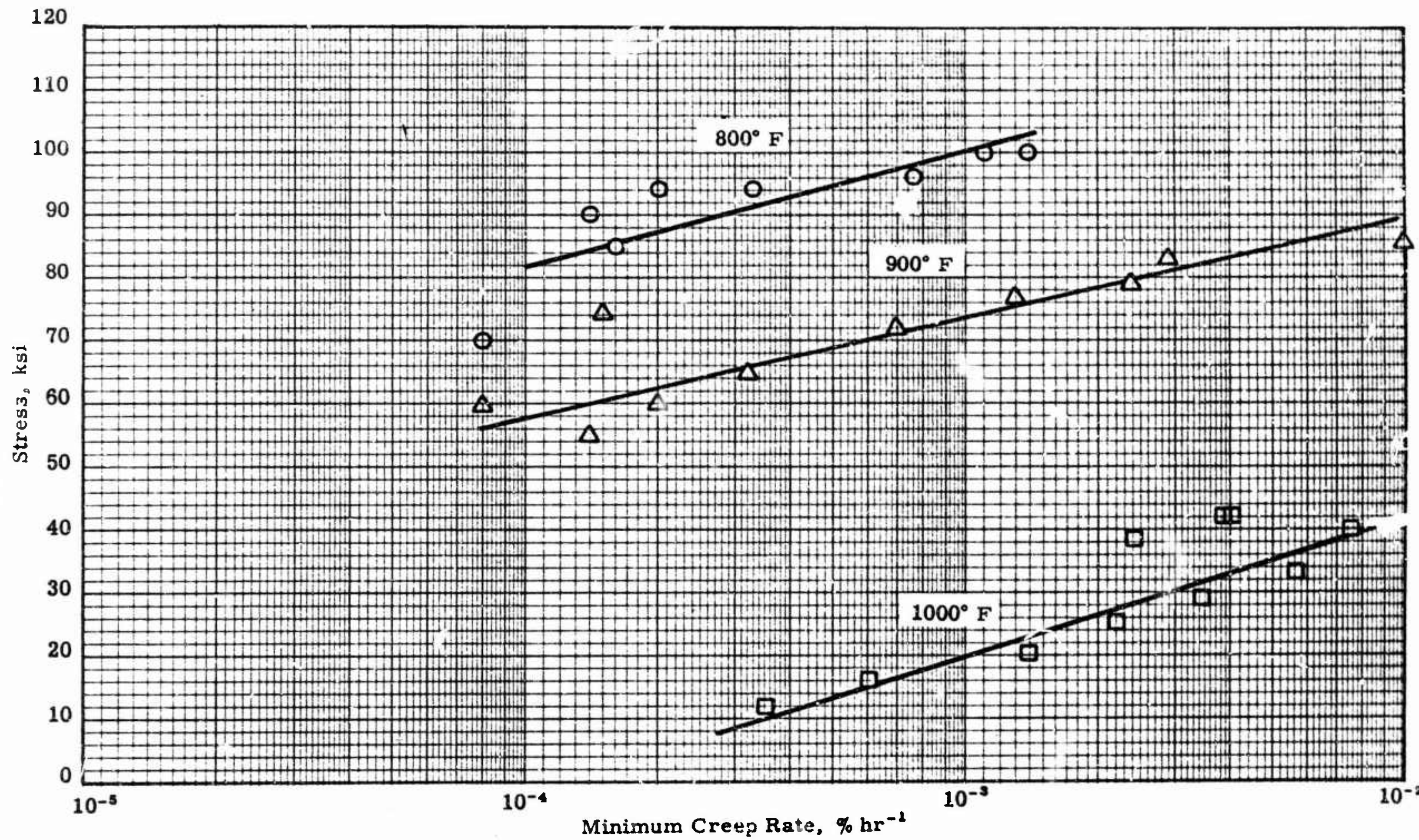


Figure 131. Minimum Creep Rate of Ti-679 Alloy Bar at Different Temperatures

Heat No. D-7274
Section Size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

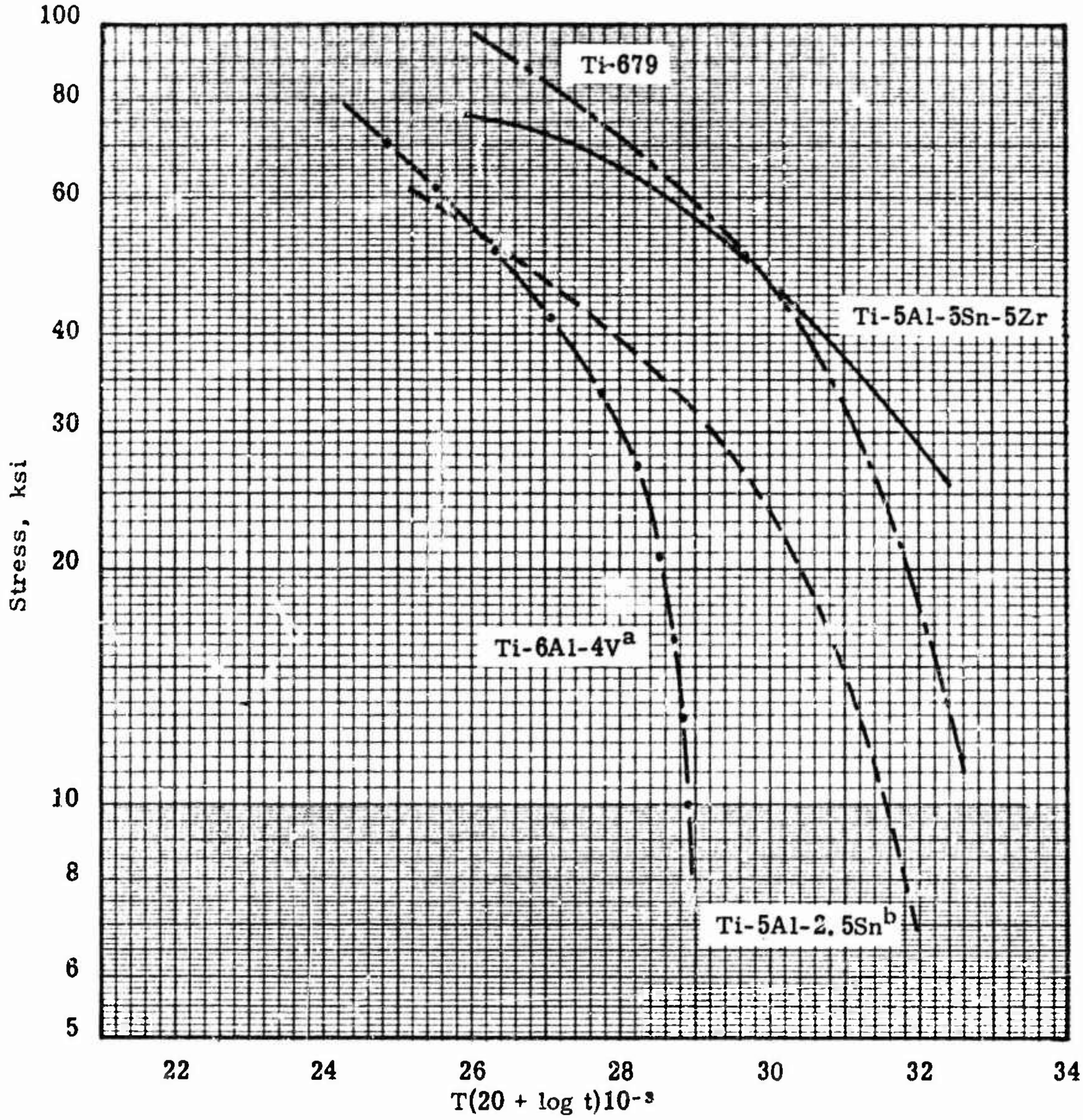


Figure 132. Comparison of Creep Strength at 0.1% Creep Deformation of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys

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Referenced Data

a - Aerospace Hdbk, Vol II, Code 3707, p 13
Properties of Ti-6Al-4V, TMCA

b - Aerospace Hdbk, Vol II, Code 3706, p 7

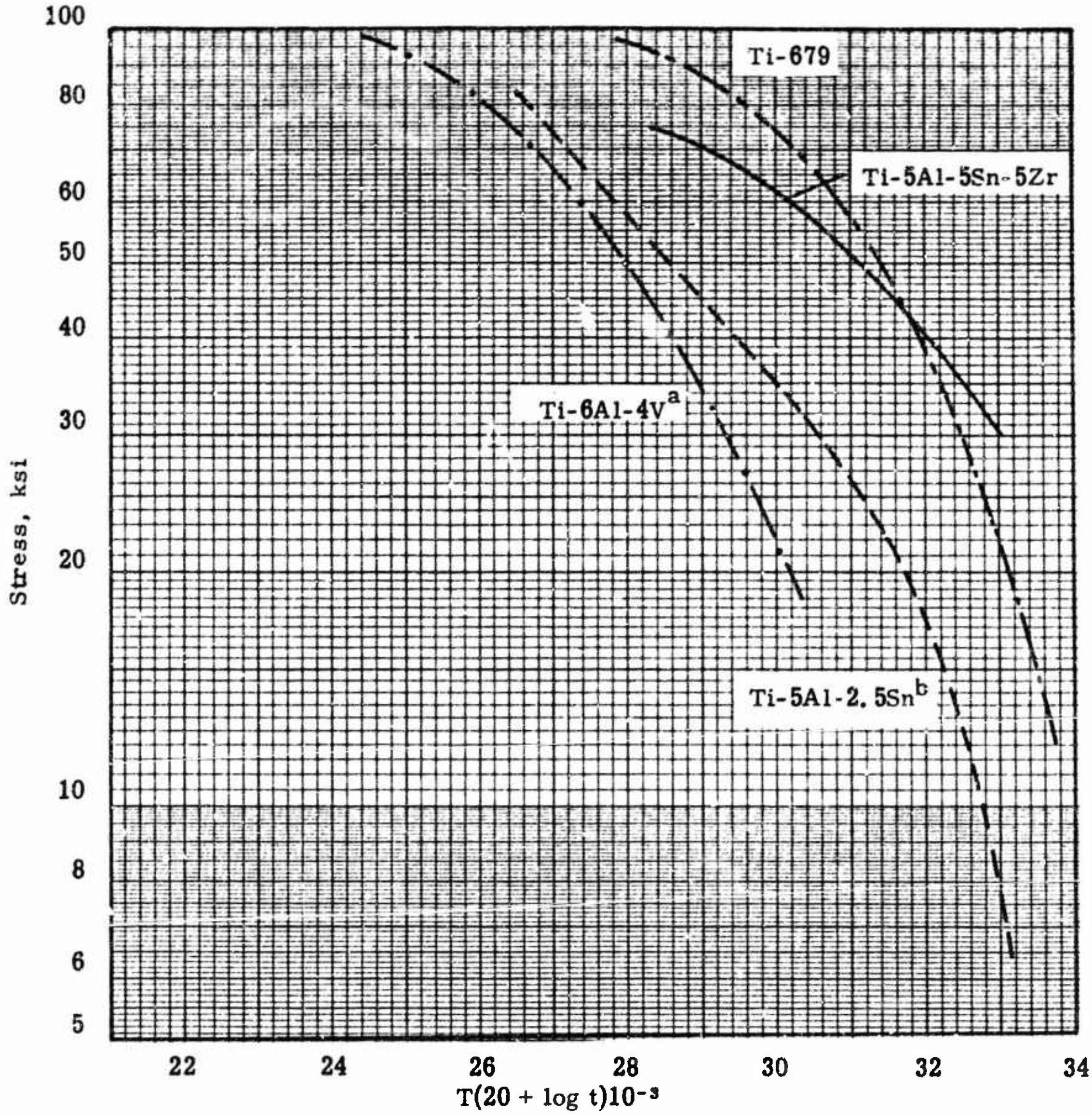


Figure 133. Comparison of Creep Strength at 0.5% Creep Deformation of Titanium Bar Alloys Evaluated in this Program with Data from the Literature for Other Titanium Alloys

Referenced Data

a - Aerospace Hdbk, Vol II, Code 3707, p 13
Properties of Ti-6Al-4V, TMCA

b - Aerospace Hdbk, Vol II, Code 3706, p 7

Table 28

Averaged Impact Strength for the Ti-5Al-5Sn-5Zr Bar Alloy[a, b, c]

Temp., °F	Impact Strength ft-lb
70	11.5
400	21.7
600	30.8
800	42.7

a Heat No. D-8060

b Section size: 1/2 in. x 1-1/8 in.

c Heat treatment: 1650° F, 2 hr, A.C.

Table 29

Averaged Impact Strength for the Ti-679 Bar Alloy[a, b, c]

Temp., ° F	Impact Strength ft-lb
70	14.3
400	17.6
600	24.5
800	30.1

a Heat No. D-7274
b Section size: 1/2 in. x 1-1/8 in.
c Heat treatment: 1650° F, 2 hr, A.C.
+ 930° F, 24 hr, A.C.

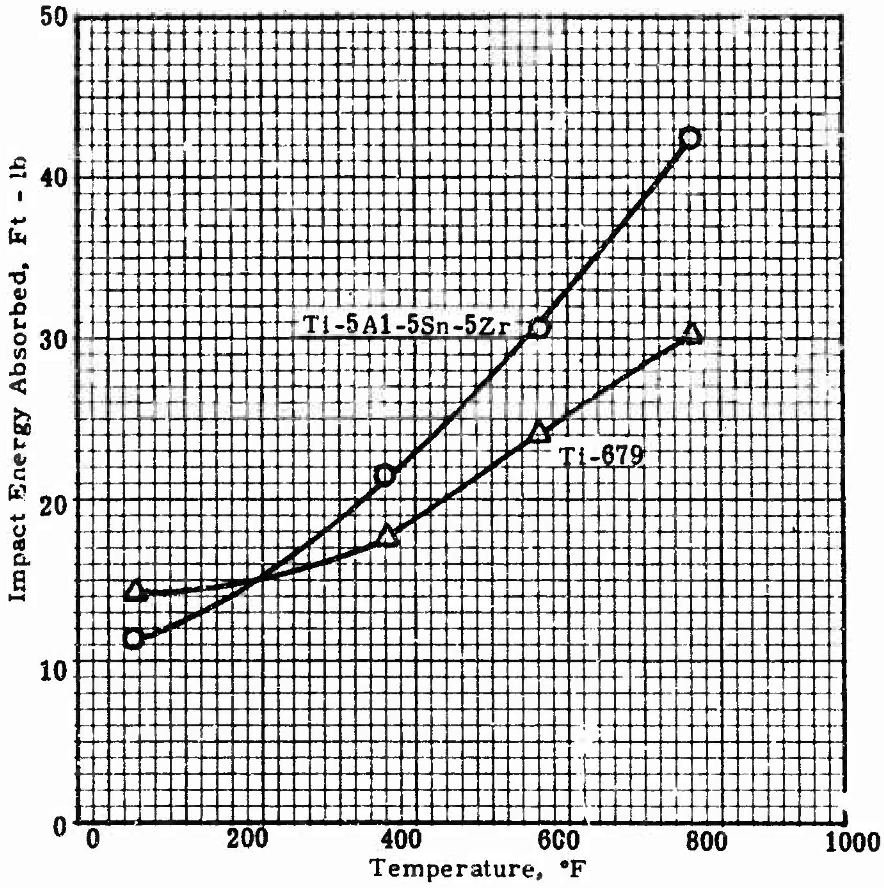


Figure 134. The Effect of Temperature on the Impact Strength of the Ti-5Al-5Sn-5Zr and Ti-679 Bar Alloys

Heat treatment and heat number

Ti-5A-5Sn-5Zr: 1650°F, 2 hr, A. C., D-8060
Ti-679: 1650°F, 2 hr, A. C. + 930°F + 24 hr, A.C., D-7274
Section: 1/2 in. x 1 1/8 in.

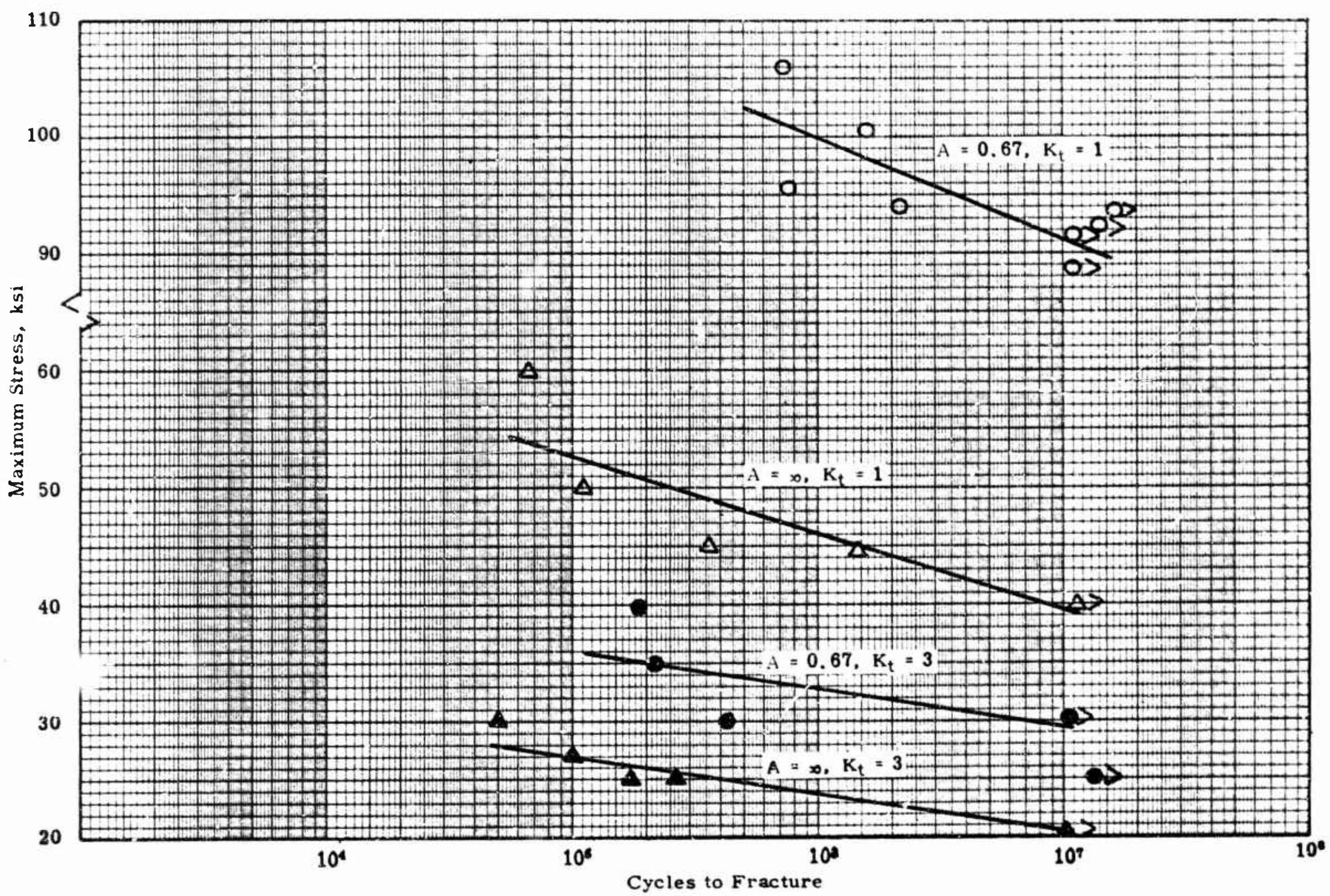


Figure 135. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Bar at 70°F in the Notched and Unnotched Conditions

Heat No. D-8060
Section size: 1 1/8 in. x 1/2 in.
Heat treatment: 1650°F, 2 hr, A. C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

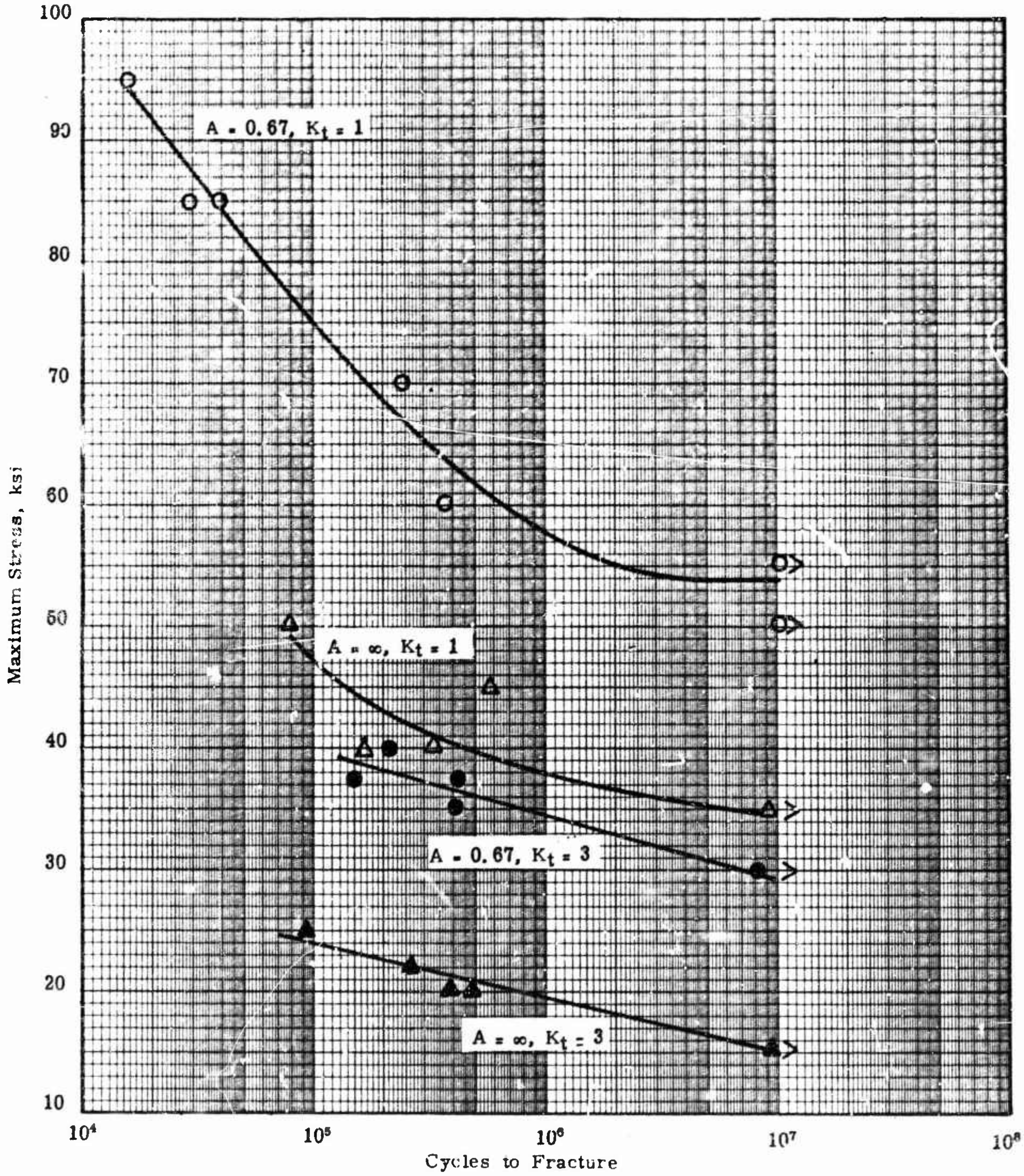


Figure 136. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Bar at 400° F in the Notched and Unnotched Conditions

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

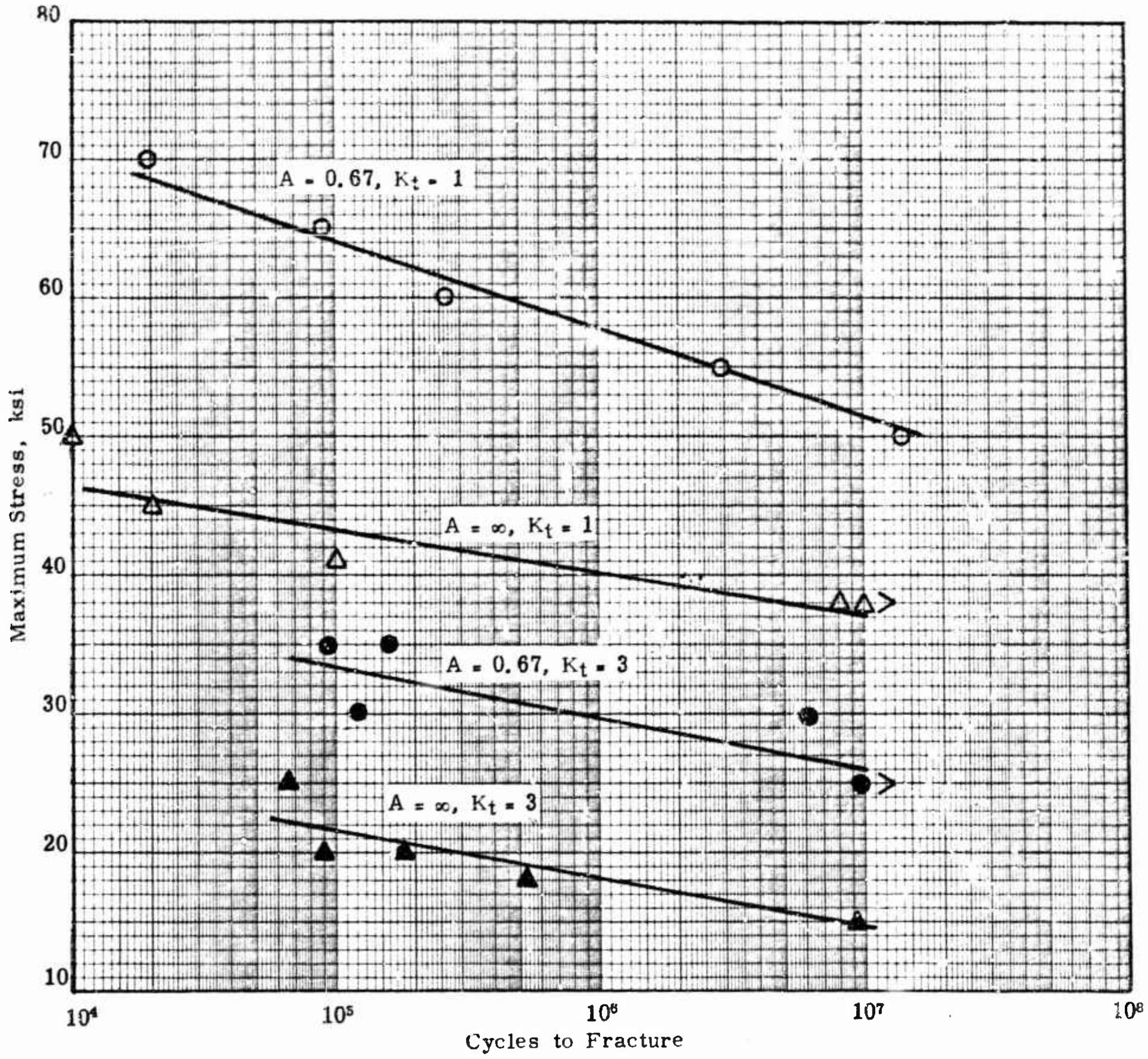


Figure 137. S-N Curves for the Ti-5Al-5Sn-5Zr Alloy Bar at 800° F in the Notched and Unnotched Conditions

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650°F, 2 hr, A.C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

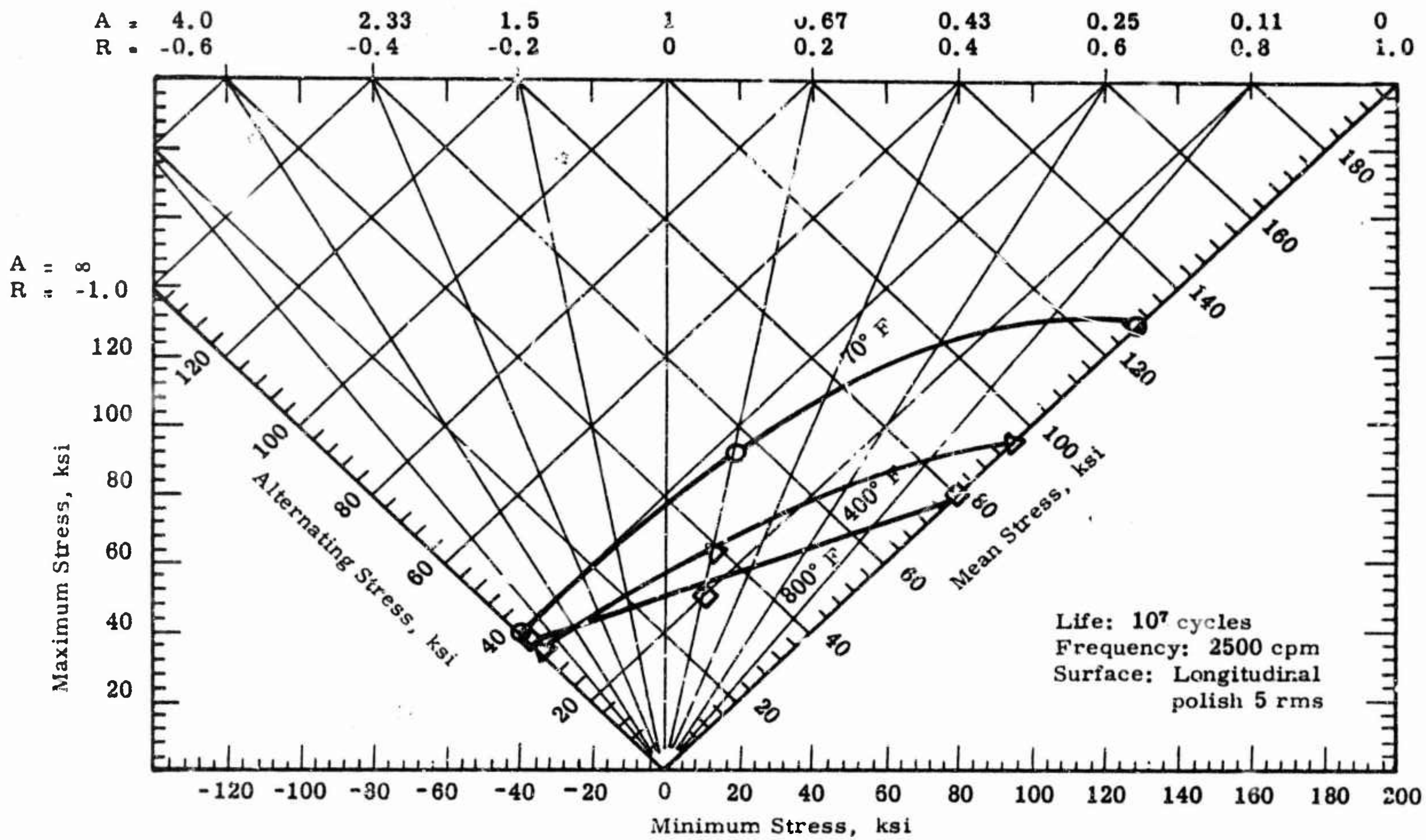


Figure 138. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr Alloy Bar (Unnotched) at Different Temperatures

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C.

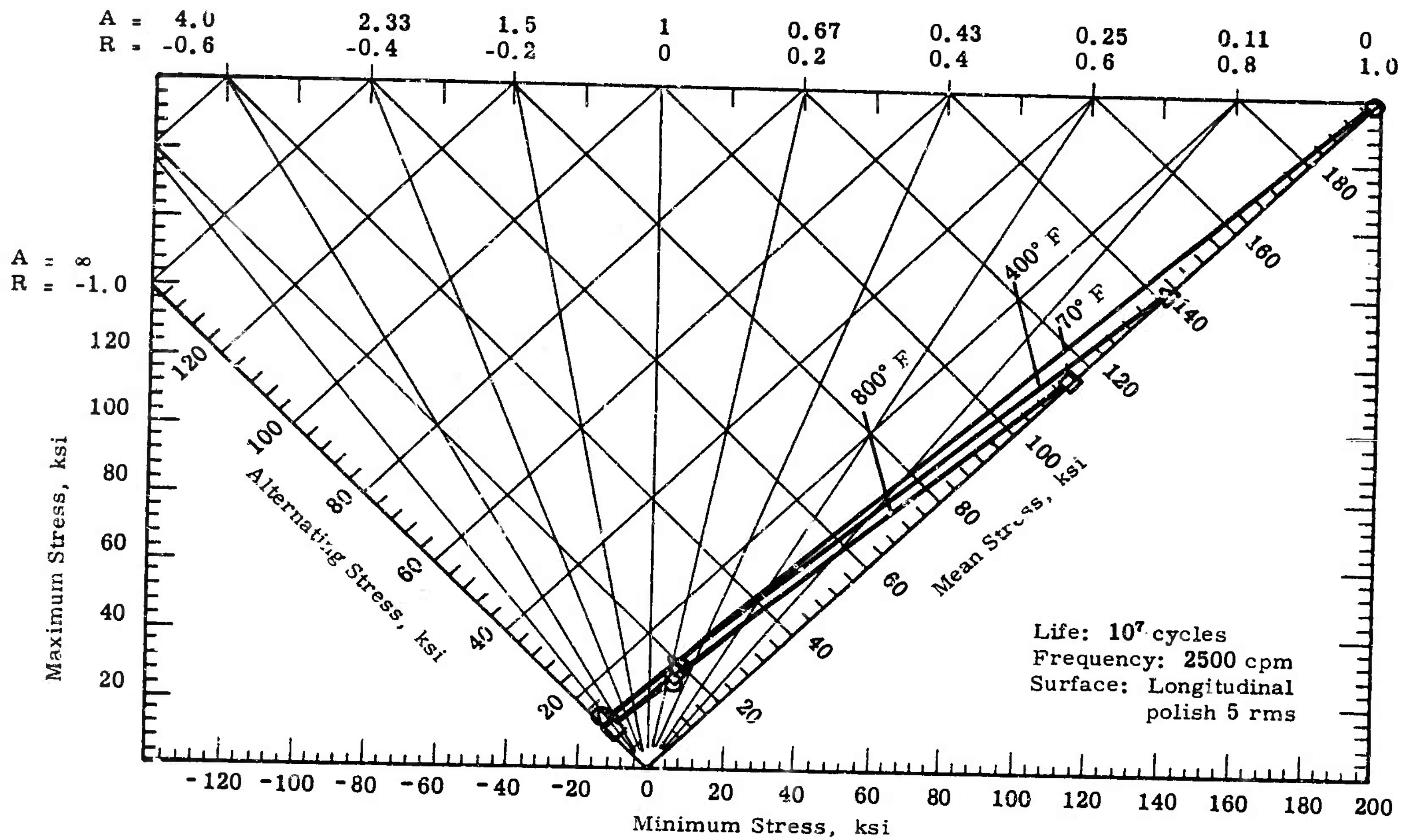


Figure 139. Constant-Life Fatigue Diagram for the Ti-5Al-5Sn-5Zr Alloy Bar (Notched $K_t = 3$) at Different Temperatures

Heat No. D-8060
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C.

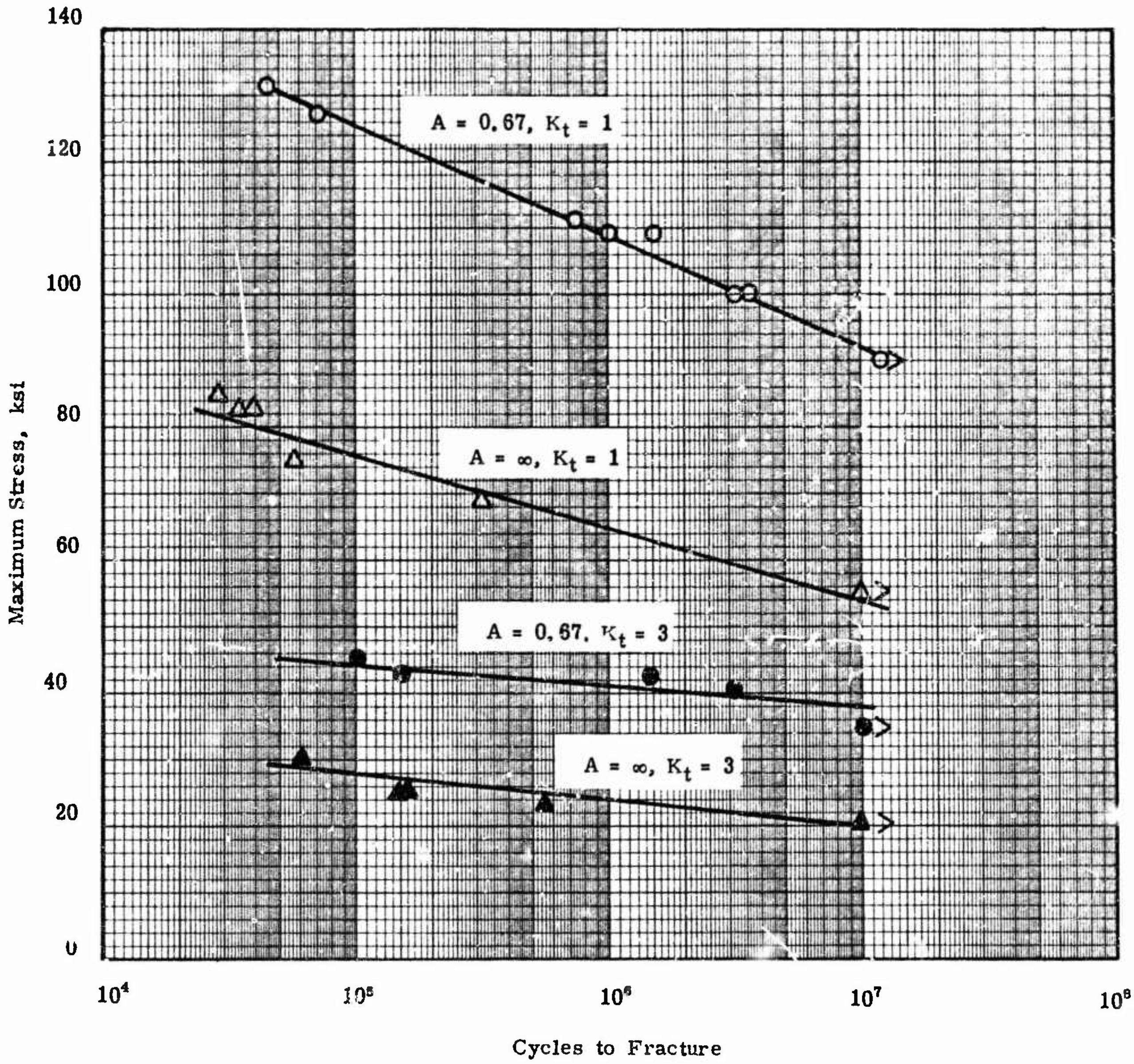


Figure 140. S-N Curves for the Ti-679 Alloy Bar at 70° F in the Notched and Unnotched Conditions.

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

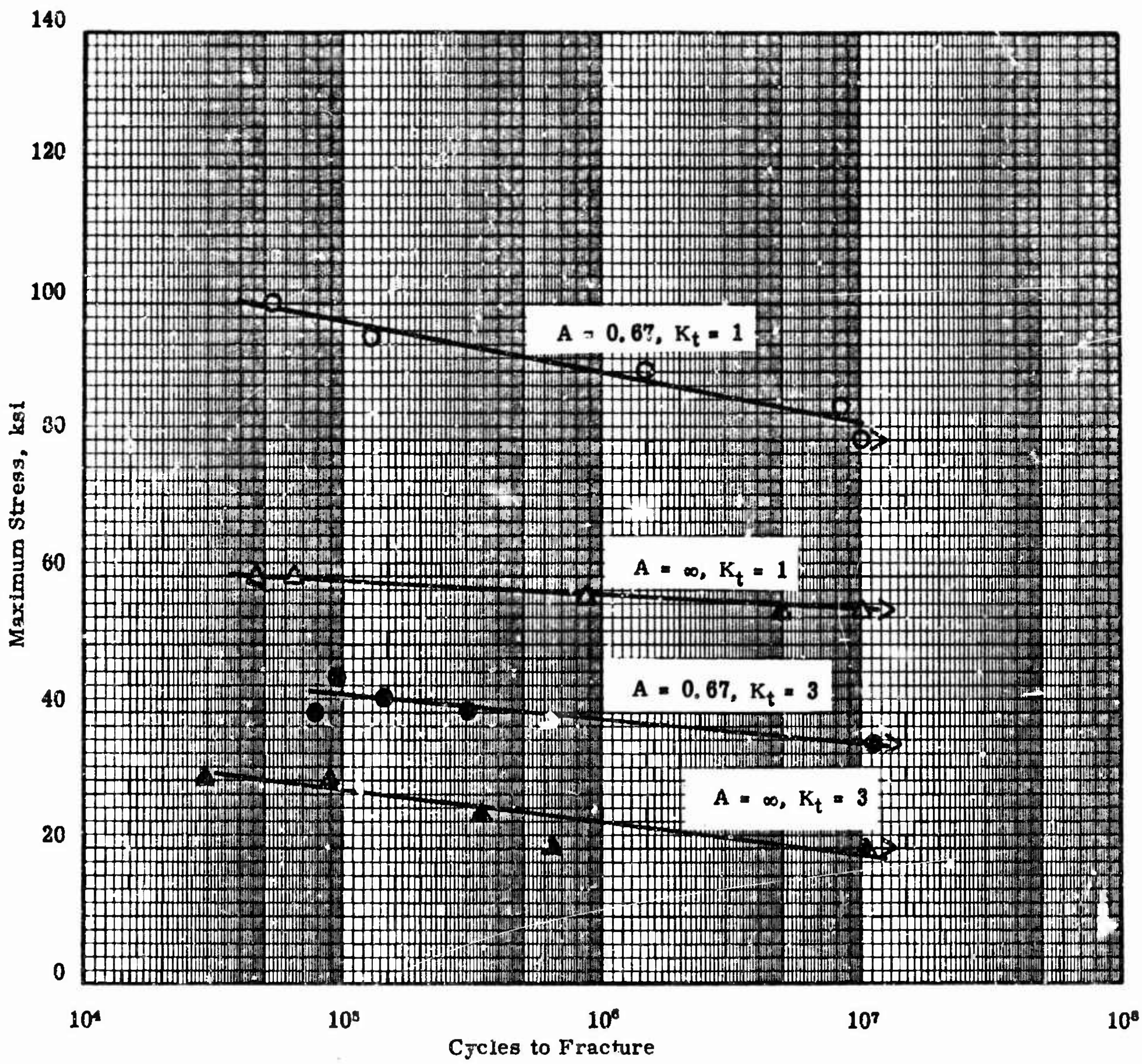


Figure 141. S-N Curves for the Ti-679 Alloy Bar at 400° F in the Notched and Unnotched Conditions.

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

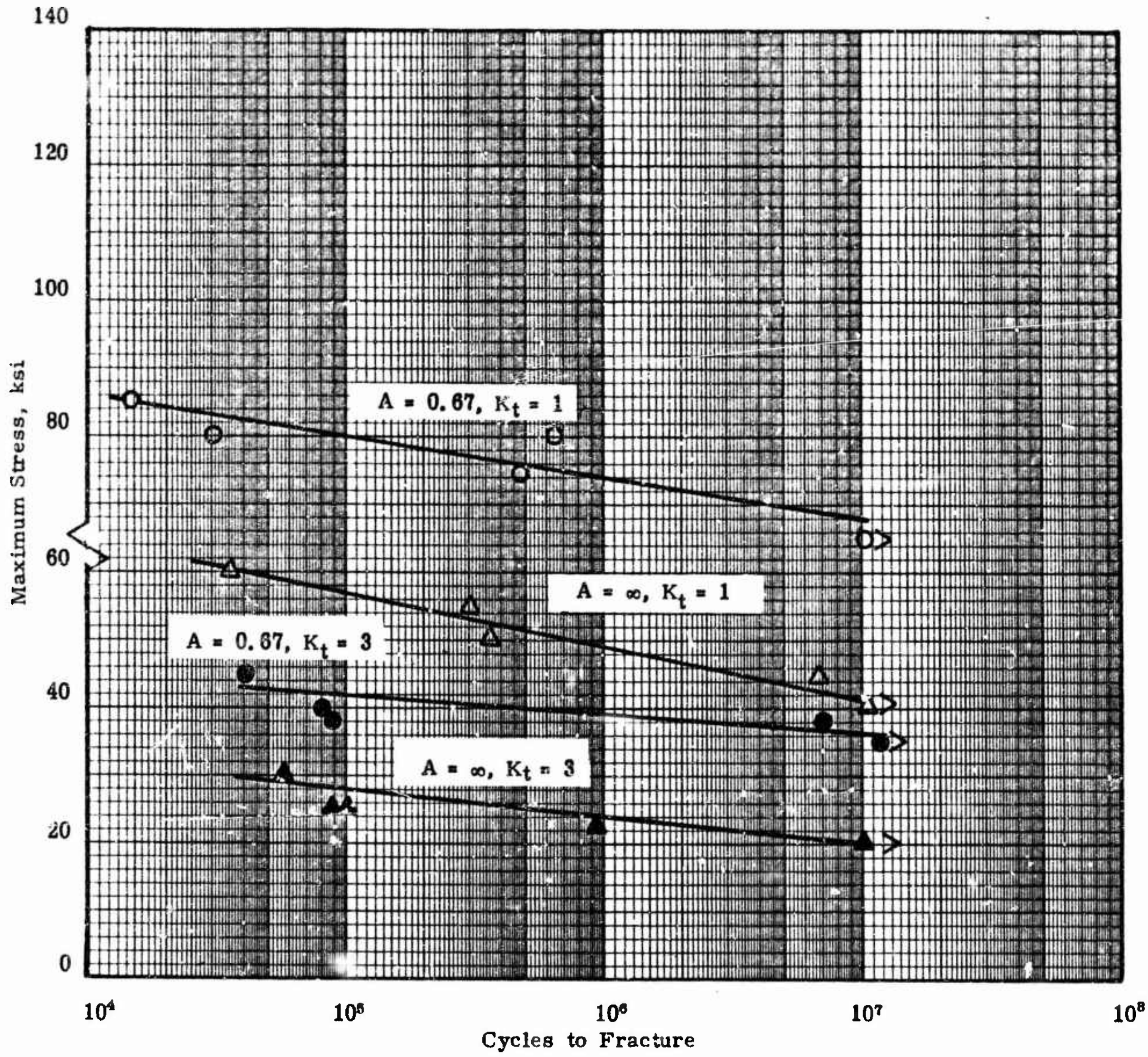


Figure 142. S-N Curves for the Ti-679 Alloy Bar at 800° F in the Notched and Unnotched Conditions.

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

$$A = \frac{\text{Alternating Stress}}{\text{Mean Stress}}$$

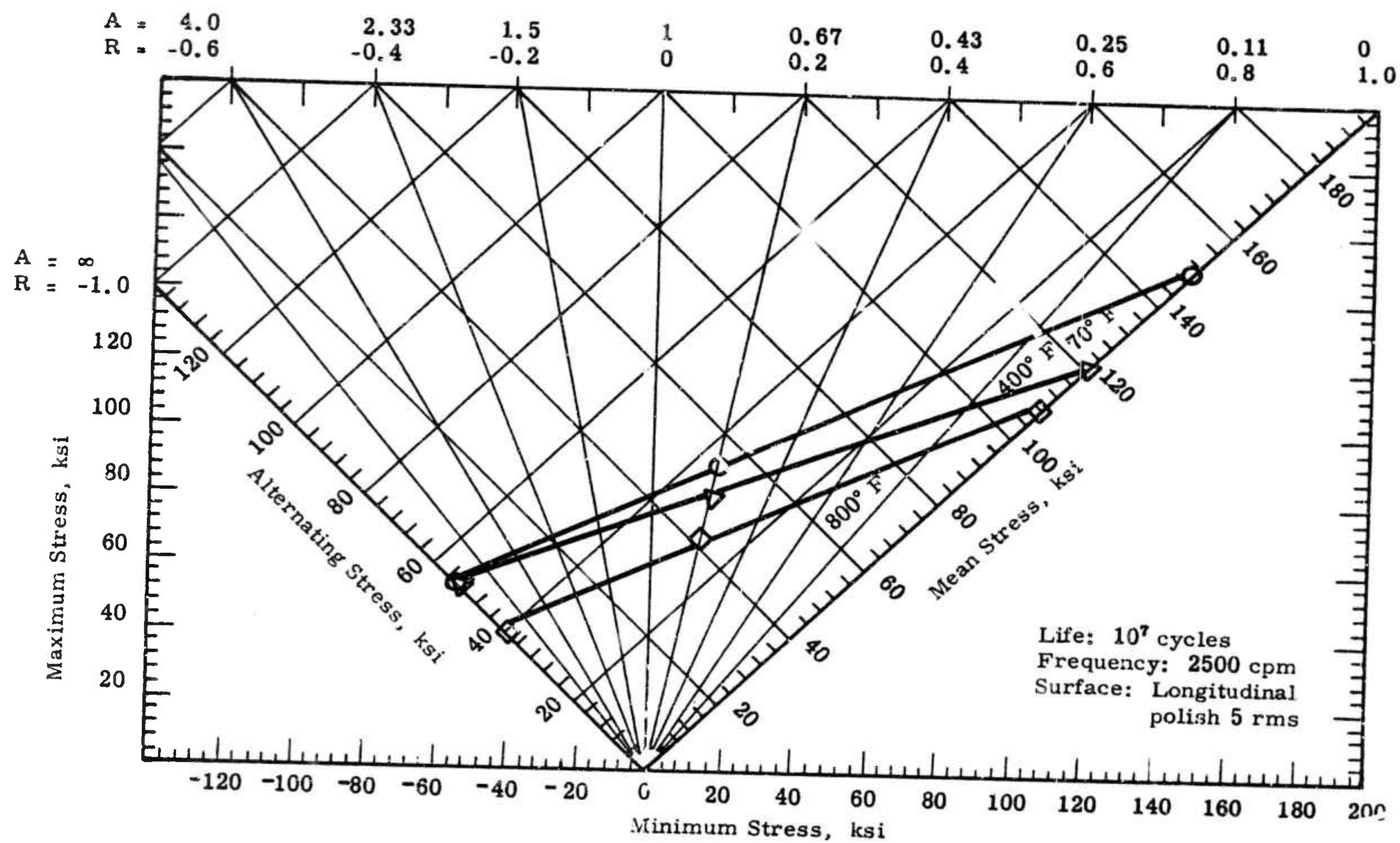


Figure 143. Constant-Life Fatigue Diagram for the Ti-679 Alloy Bar (Unnotched) at Different Temperatures

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A. C. + 930° F, 24 hr, A.C.

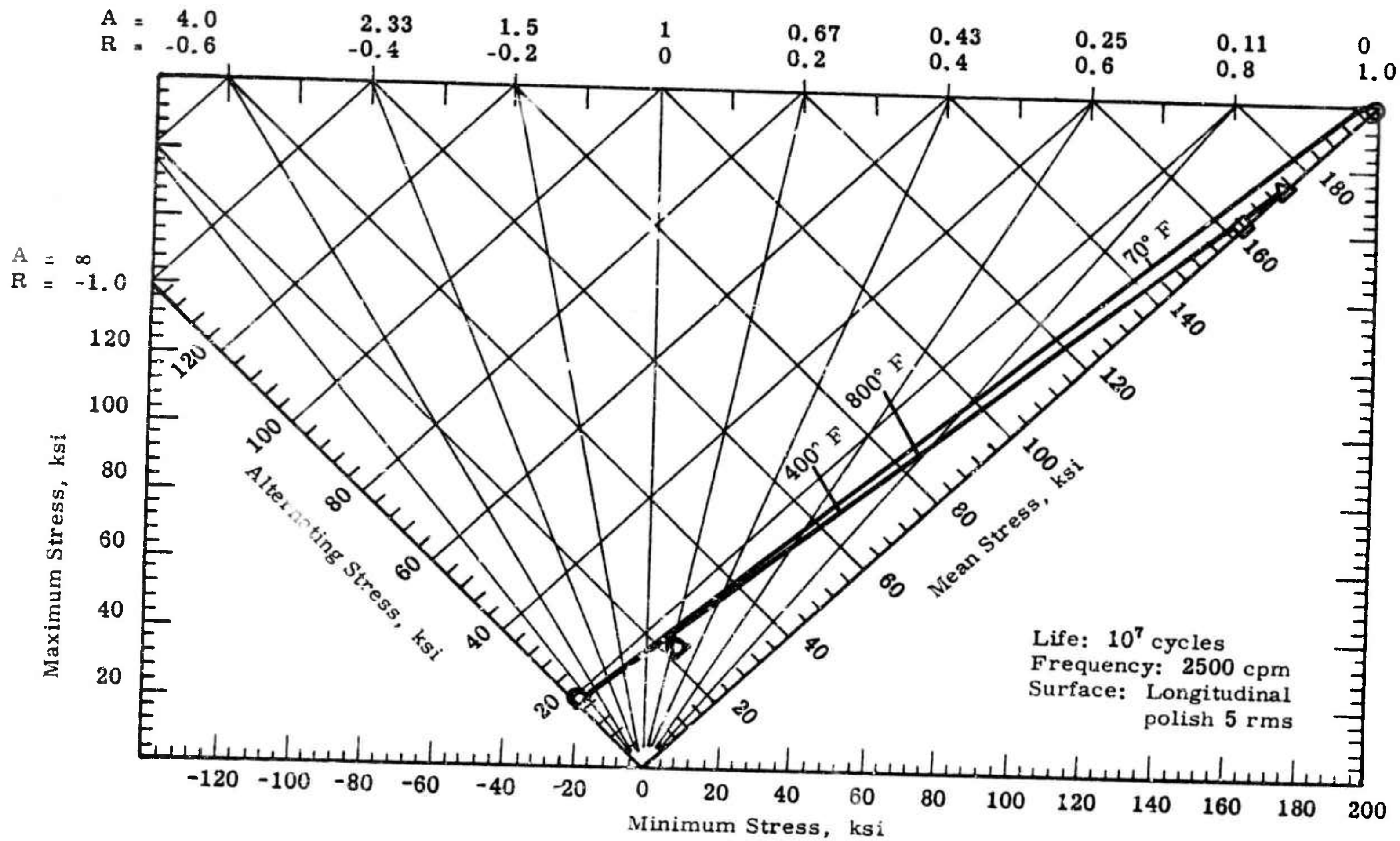


Figure 144. Constant-Life Fatigue Diagram for the Ti-679 Alloy Bar (Notched K_t = 3) at Different Temperatures

Heat No. D-7274
Section size: 1-1/8 in. x 1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

The constant-life fatigue diagrams (Figures 135 and 140) show that the Ti-679 alloy had higher fatigue strength than the Ti-5Al-5Sn-5Zr alloy in the unnotched condition. Figures 136 and 141 show that the fatigue strength of the Ti-679 bar was also slightly higher than that of the Ti-5Al-5Sn-5Zr bar in the notched condition.

Fracture Toughness

Values of the apparent fracture toughness for the bar alloys are given in Table 30 and Table 88 (Appendix I). As was the case for the sheet alloys, gross plastic yielding in advance of the crack occurred, which prevented calculation of the true fracture toughness. Tables 30 and 88 are clearly marked to indicate that the calculated values represented only the apparent fracture toughness. The criterion[8] that has been used to judge the validity of the calculated plane-strain fracture toughness for a single-edge-notched specimen is that the nominal stress at the crack tip (σ nom) should not exceed the yield strength. As Table 88 shows, σ nom/F_{ty} was generally greater than 1.0, indicating that the calculated values are not representative of the true fracture toughness of the bar alloys.

Dynamic Modulus of Elasticity

The dynamic moduli of elasticity of the bar alloys is shown by data in Table 31 and Figure 145.

These data are in agreement with the precision modulus of elasticity determinations and the moduli as determined from the tensile stress-strain curves, in that the modulus of the Ti-679 alloy appears to be slightly lower than that of the Ti-5Al-5Sn-5Zr bar at most temperatures.

Table 30

Summary of Apparent Fracture-Toughness of the Bar Alloys

Notice: Gross yielding occurred in tests at 400 and 70° F, and to some extent at -110° F, such that the true fracture toughness is not represented by data given in this table.

Alloy	Temp., °F	K_{nc}[a] ksi $\sqrt{in.}$
Ti-5Al-5Sn-5Zr	400	49.4
Ti-5Al-5Sn-5Zr	70	69.1
Ti-5Al-5Sn-5Zr	-110	55.7
Ti-679	400	54.8
Ti-679	70	60.8
Ti-679	-110	52.7

a Stress intensity factor reported as K_{nc}, rather than K_{Ic}, because pop-in was not observed and calculation was based on load deviation from linearity.

Table 31

The Dynamic Moduli of Elasticity at Different Temperatures of the Ti-5Al-5Sn-5Zr and Ti-679 Alloys in Bar Form[a]

Alloy	E, 10^6 psi 70° F	400° F	600° F	800° F	1000° F
Ti-5Al-5Sn-5Zr[b]	16.88	15.56	14.65	13.75	12.75
Ti-679[b]	15.37	14.09	13.47	12.64	11.91

[a] Section size: 1/2 in. x 1-1/8 in.

[b] Heat treatments:
Ti-5Al-5Sn-5Zr: 1650° F, 2 hr, A.C.
Ti-679: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

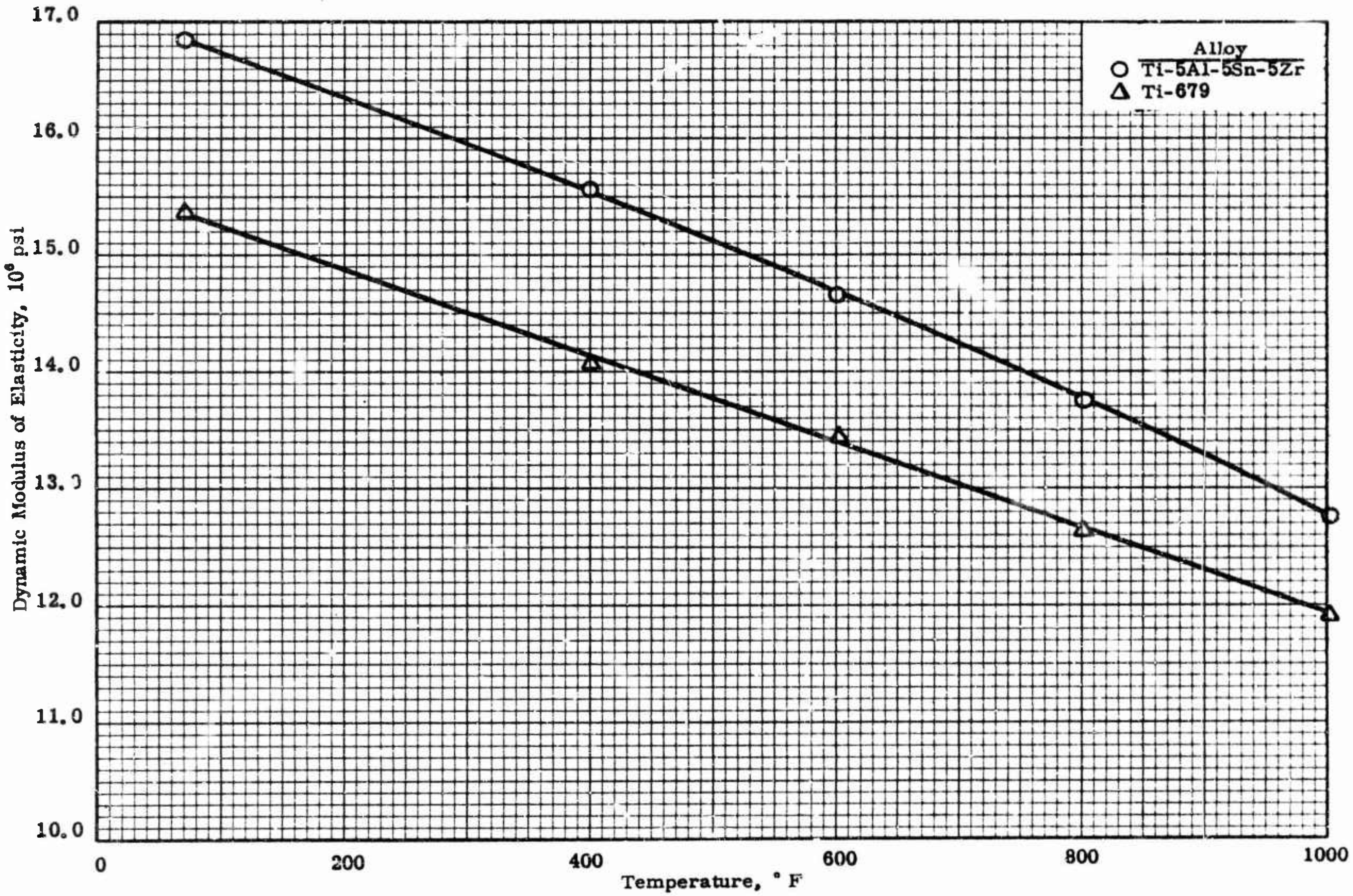


Figure 145. The Effect of Temperature on the Moduli of Elasticity of the Titanium Bar Alloys under Conditions of Dynamic Loading

RESULTS OF THERMAL-PROPERTY TESTS

Thermal Conductivity

The thermal conductivities of the titanium alloys are shown in Figures 146 through 150; the data are given in Tables 89 through 93 in Appendix II, and the conductivities of all the alloys are shown in a composite plot in Figure 151. The conductivities increased with increased temperature from about 52 to 57 Btu/hr/ft²/° F/in. at 100° F to from 88 to 93 Btu/hr/ft²/° F/in. at 1000° F. The conductivity of Ti-679, as seen in Figure 150, agrees well above 500° F with a curve from the Titanium Metals Corporation of America literature but is higher at the lower temperatures. Also shown in Figure 151 is the range of data for seven titanium alloys containing from 4% to 8% aluminum plus small percentages of various other elements as compiled by the Armour Research Foundation and reported in WADC-TR-58-476. The conductivities of these four alloys were within the range shown except at above 900° F, where they were slightly lower. There was no difference in the conductivity of the Ti-5Al-5Sn-5Zr in bar and sheet form.

Thermal Expansion

The thermal expansions of the alloys are shown in Figures 152 through 159 and the data are given in Tables 94 through 101 in Appendix II. No differences in thermal expansion were detected between the alloy Ti-5Al-5Sn-5Zr in bar form and in sheet form, and no differences were detected in the expansions parallel and transverse to the rolling direction of the sheet materials. The total thermal expansion of all the materials from room temperature to 1000° F was about 5×10^{-3} in./in. and the coefficients of thermal expansion near 700° F were from 5.5 to 5.8×10^{-6} in./in./° F. A composite plot of the thermal expansions of the four alloys is given in Figure 160.

Literature values for the coefficients of thermal expansion from room temperature to about 500° F of similar alloys range generally from 5 to 5.7×10^{-6} in./in./° F.

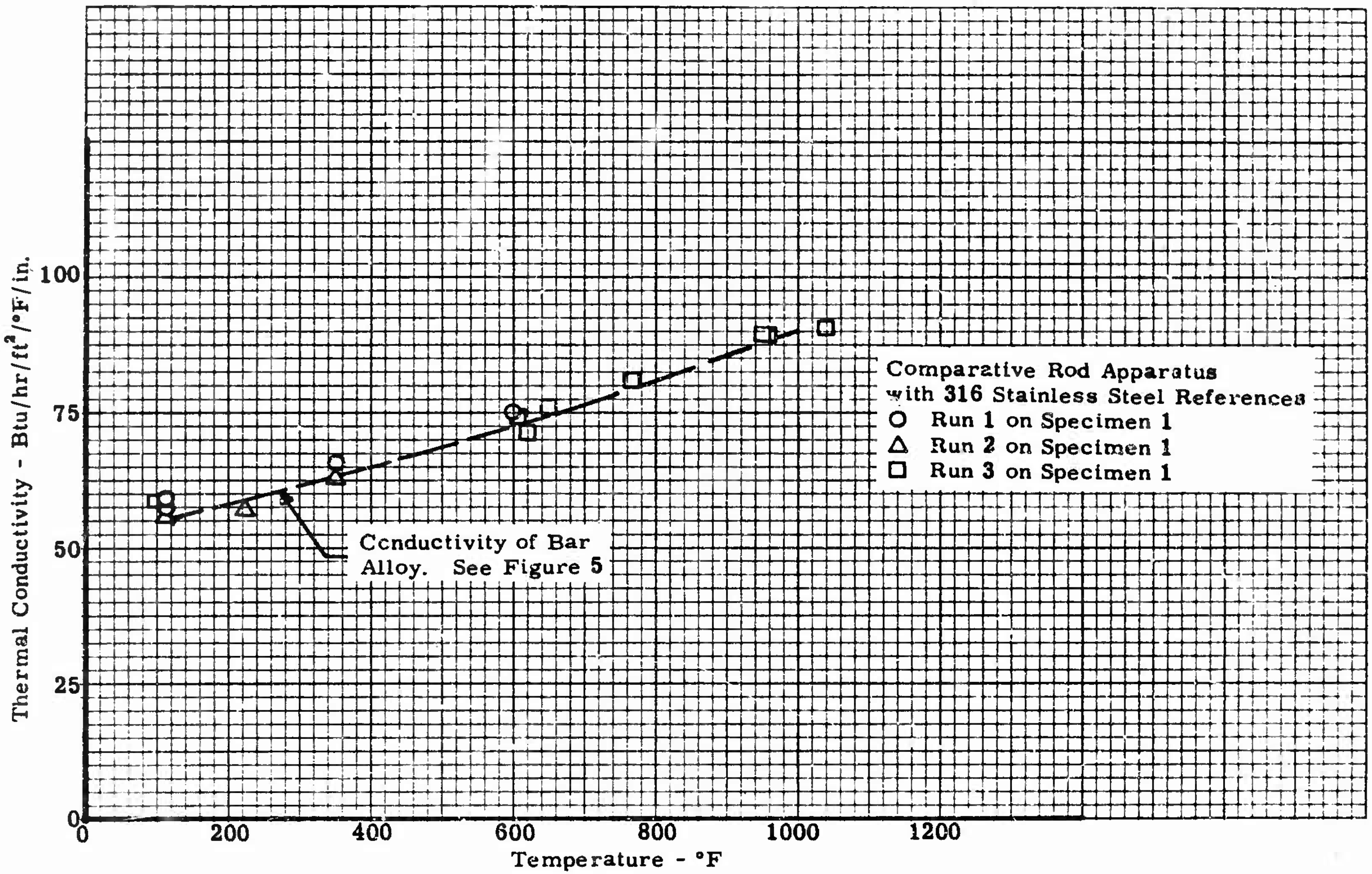


Figure 146. The Thermal Conductivity of the Titanium Sheet Alloy, Ti-5Al-5Sn-5Zr, Parallel to Rolling Direction.

Heat No. D-8060
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C.

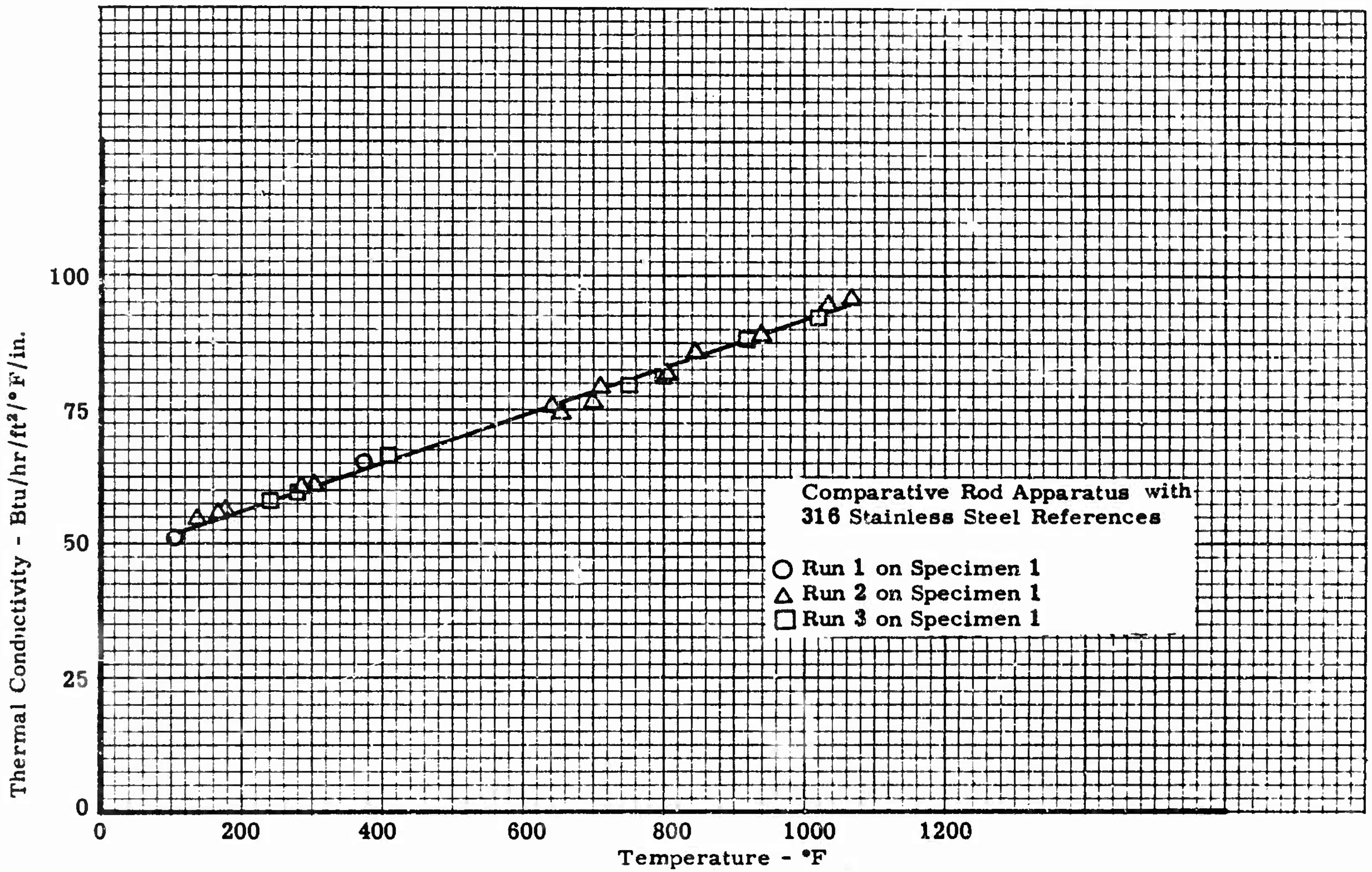


Figure 147. The Thermal Conductivity of the Titanium Sheet Alloy, Ti-5Al-5Sn-5Zr-1Mo-1V Parallel to Rolling Direction.

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

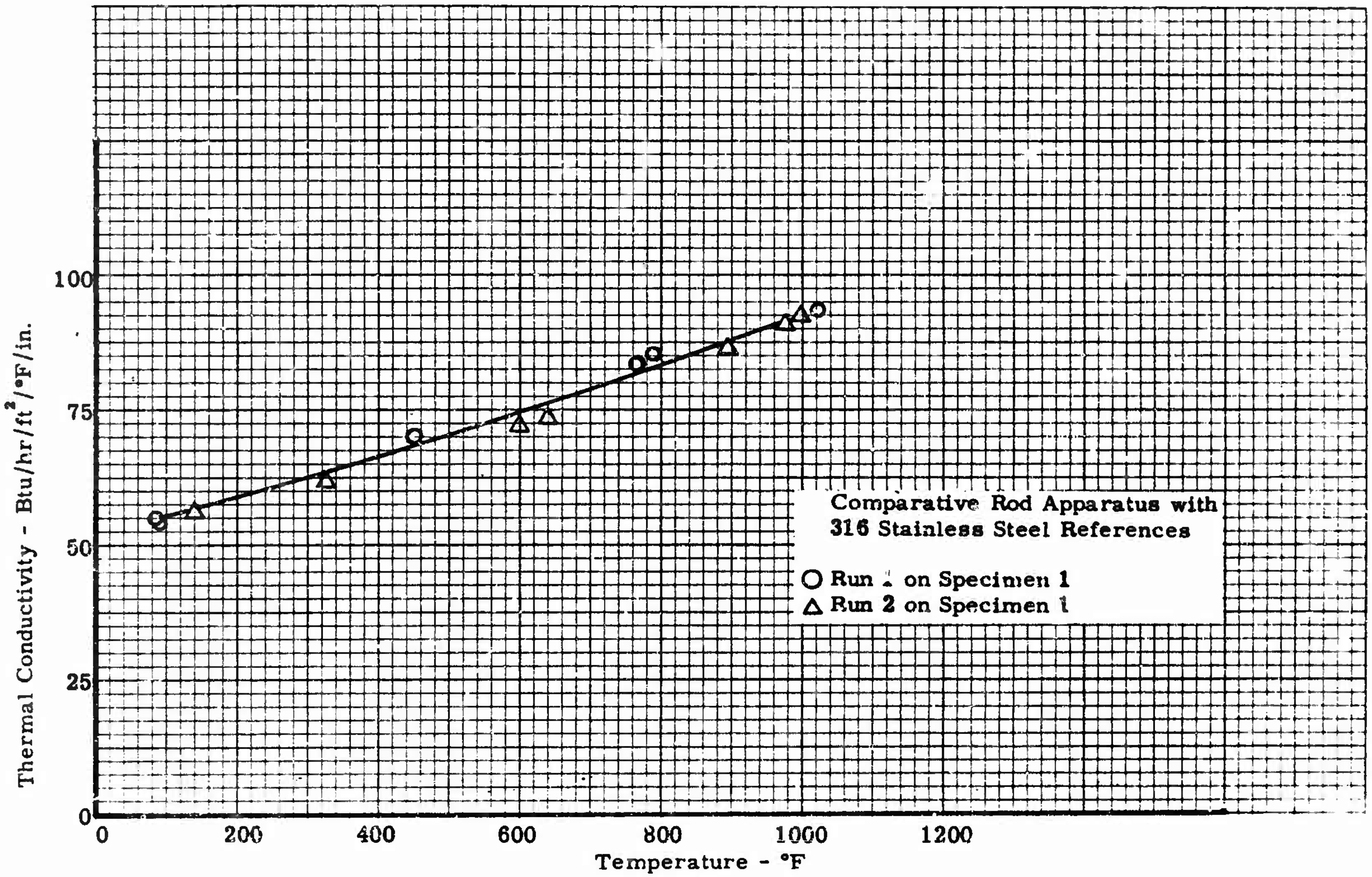


Figure 148. The Thermal Conductivity of the Titanium Sheet Alloy, Ti-6Al-2Sn-4Zr-2Mo Parallel to Rolling Direction

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

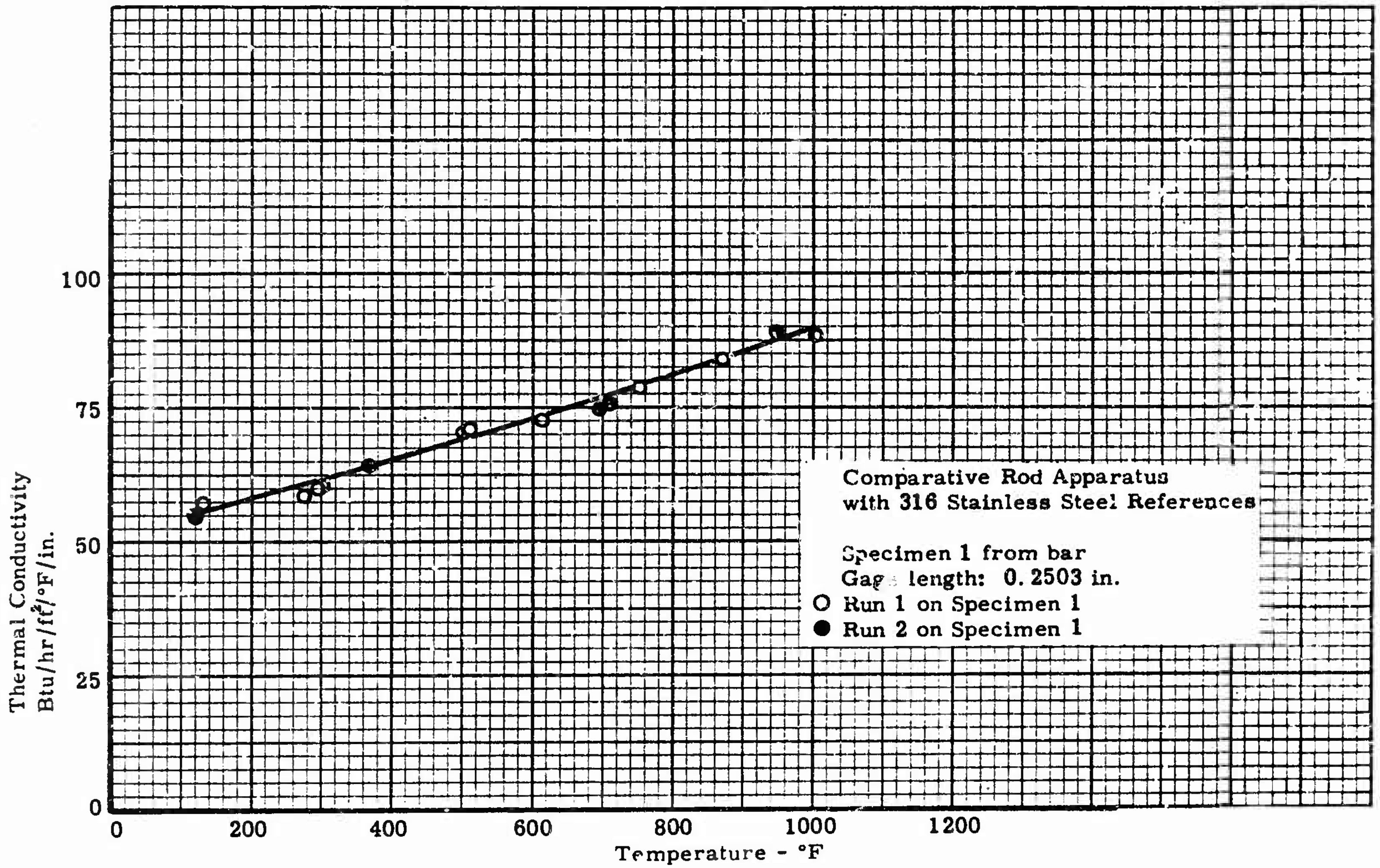


Figure 149. The Thermal Conductivity of the Titanium Bar Alloy, Ti-5Al-5Sn-5Zr Transverse to the Rolling Direction.

Heat No. D-8030
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

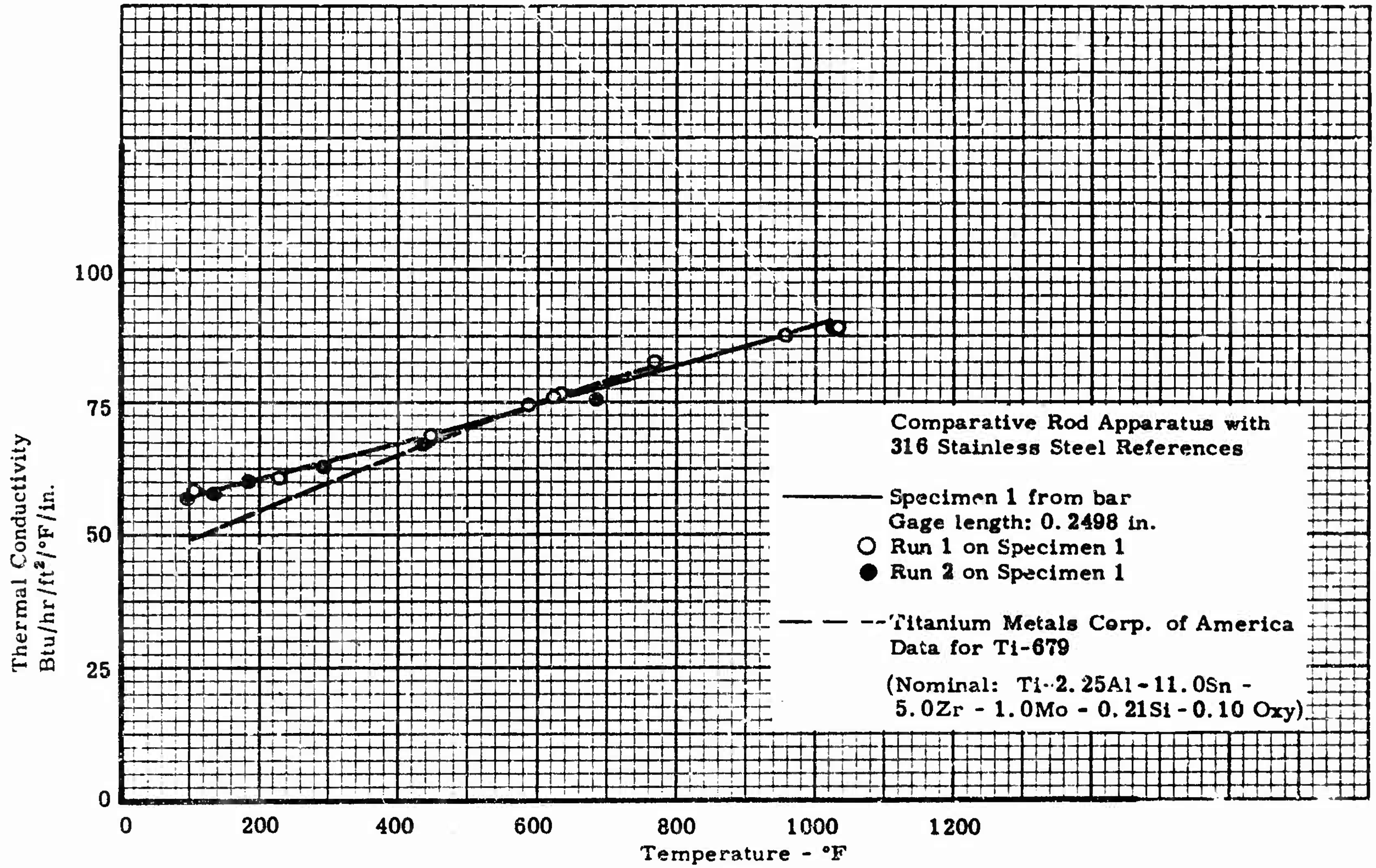


Figure 150. The Thermal Conductivity of the Titanium Bar Alloy, Ti-679 Transverse to Rolling Direction

Heat No. D-7274
Section size: 1/2 in. x 1-1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

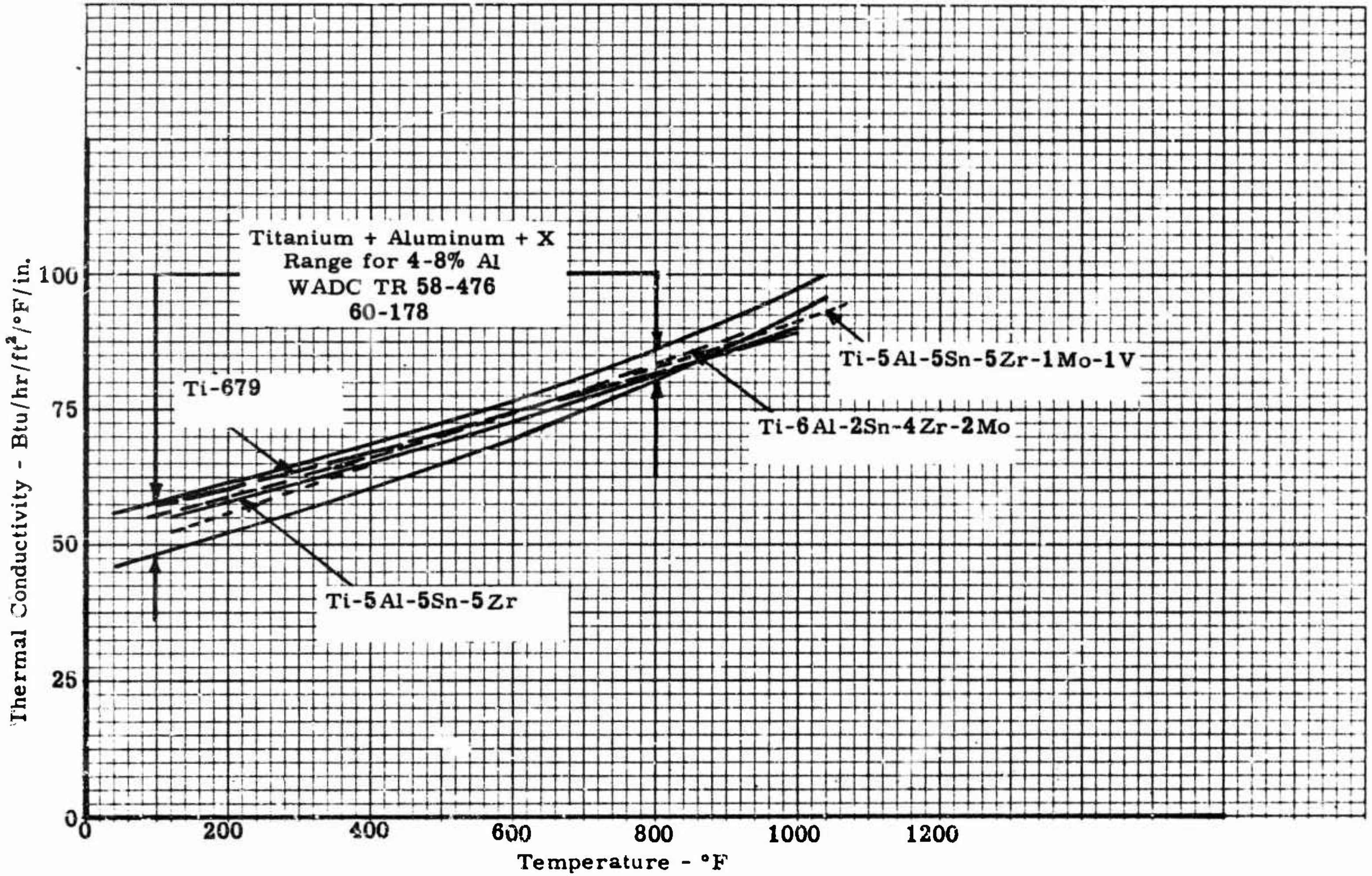


Figure 151. The Thermal Conductivities of Some Titanium Alloys.

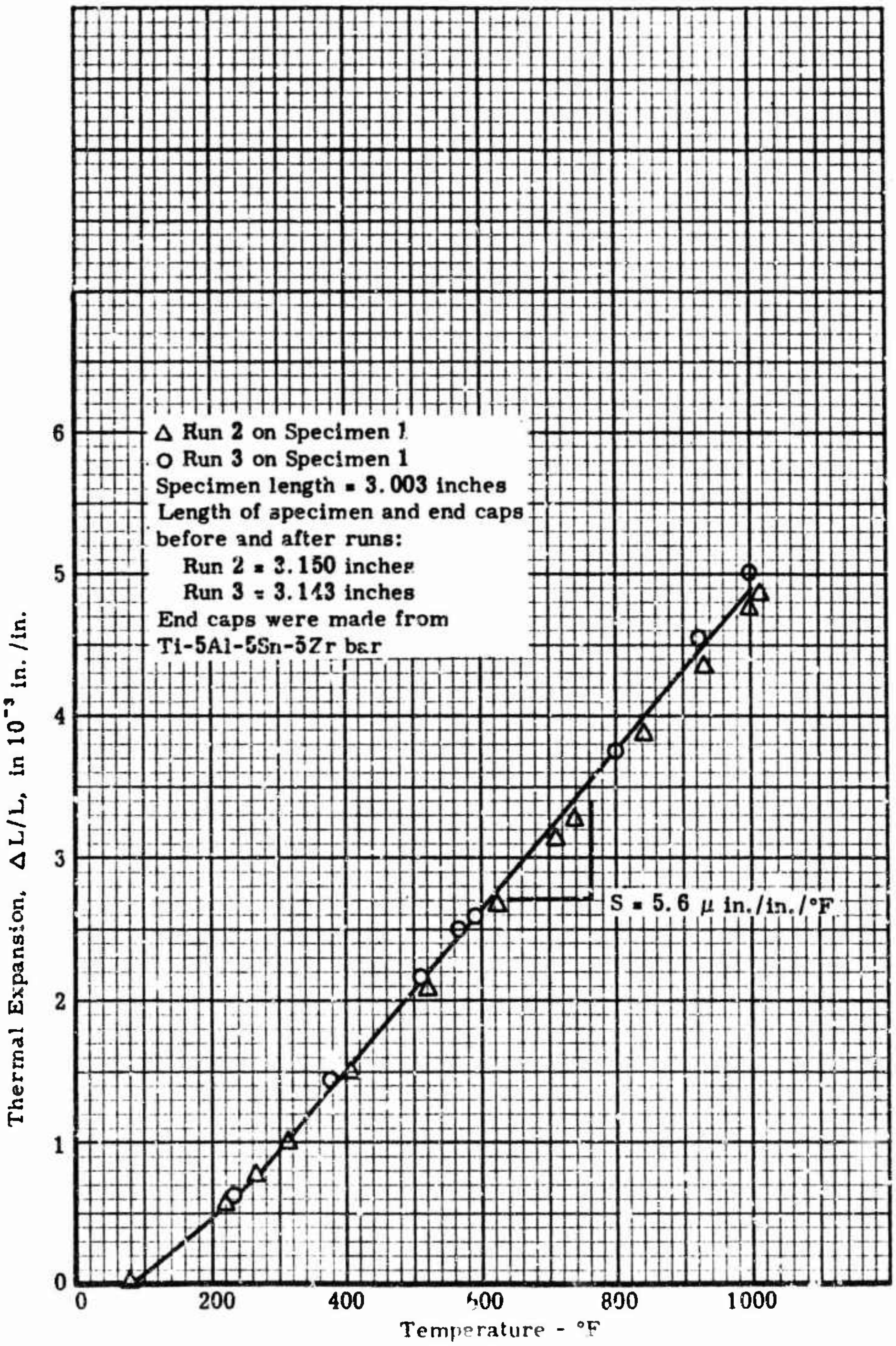


Figure 52. The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Sheet Form Parallel to the Rolling Direction.

Heat No. D-8060
Sheet thickness: 40mil
Heat Treatment: 1650° F, 1/2 hr, A.C.

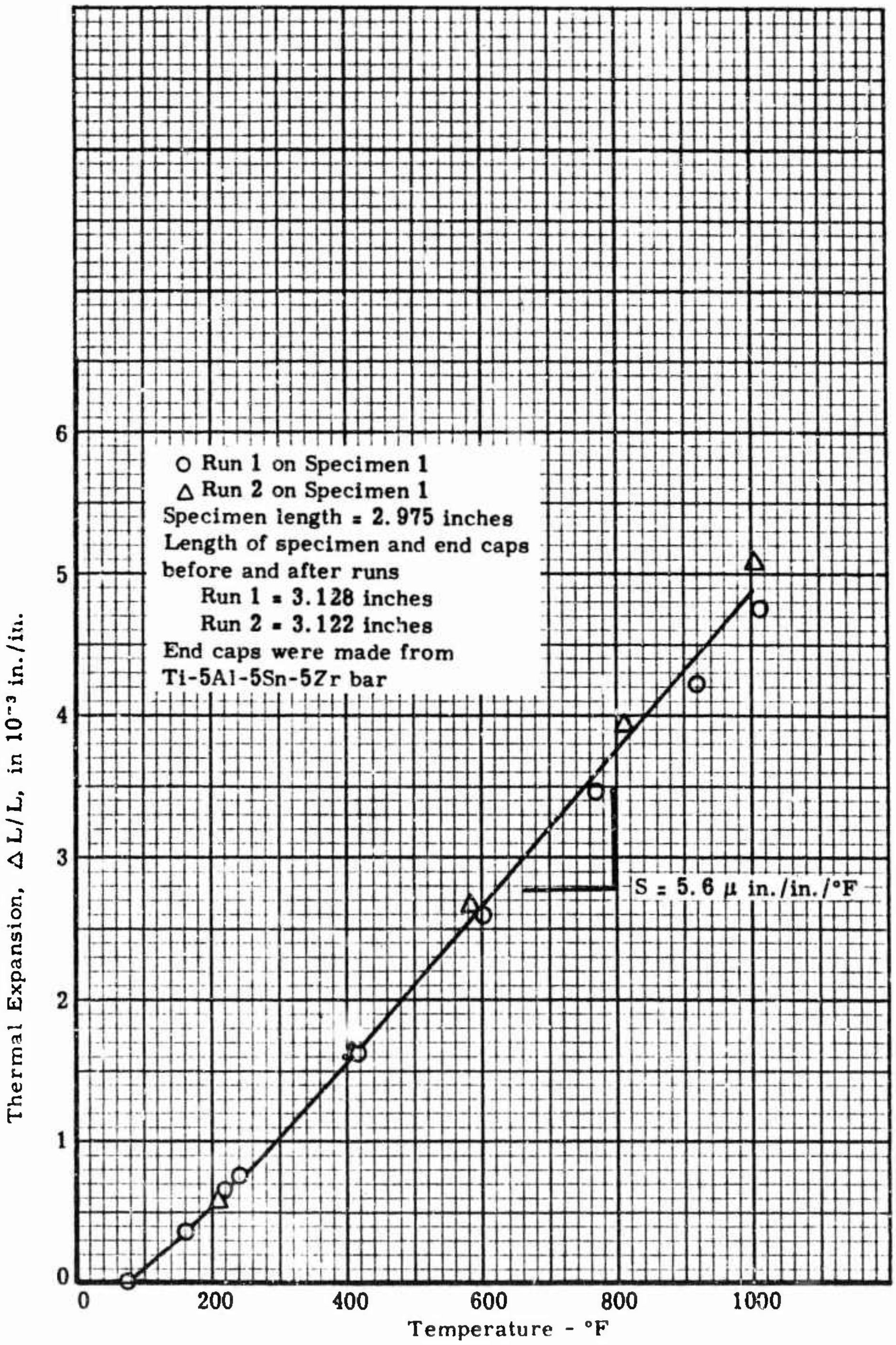


Figure 153. The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Sheet Form Transverse to the Rolling Direction

Heat No. D-8060
Sheet thickness: 40 mils
Heat treatment: 1650° F, 1/2 hr, A.C.

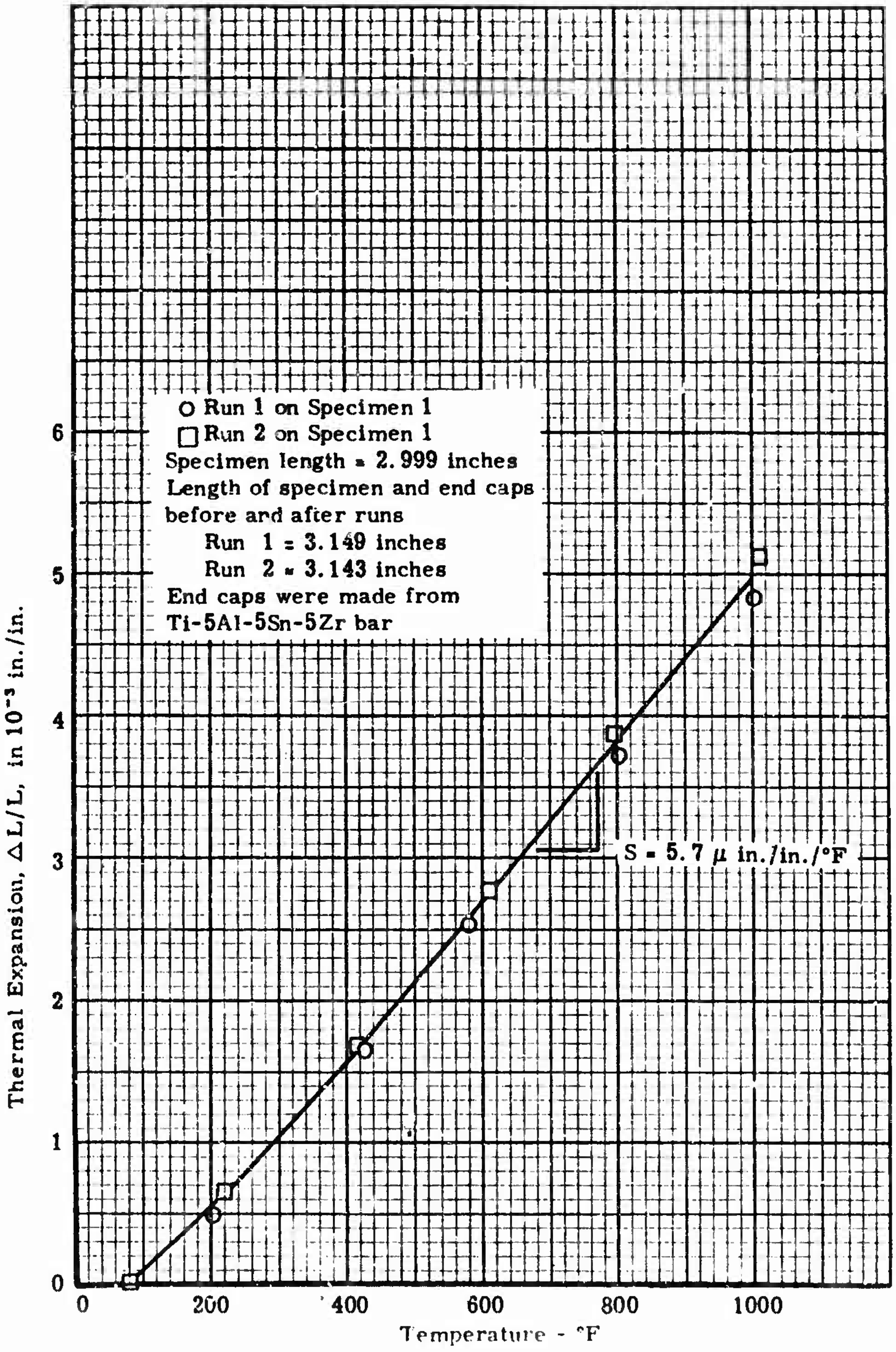


Figure 154. The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr-1Mo-1V in Sheet Form Parallel to the Rolling Direction.

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

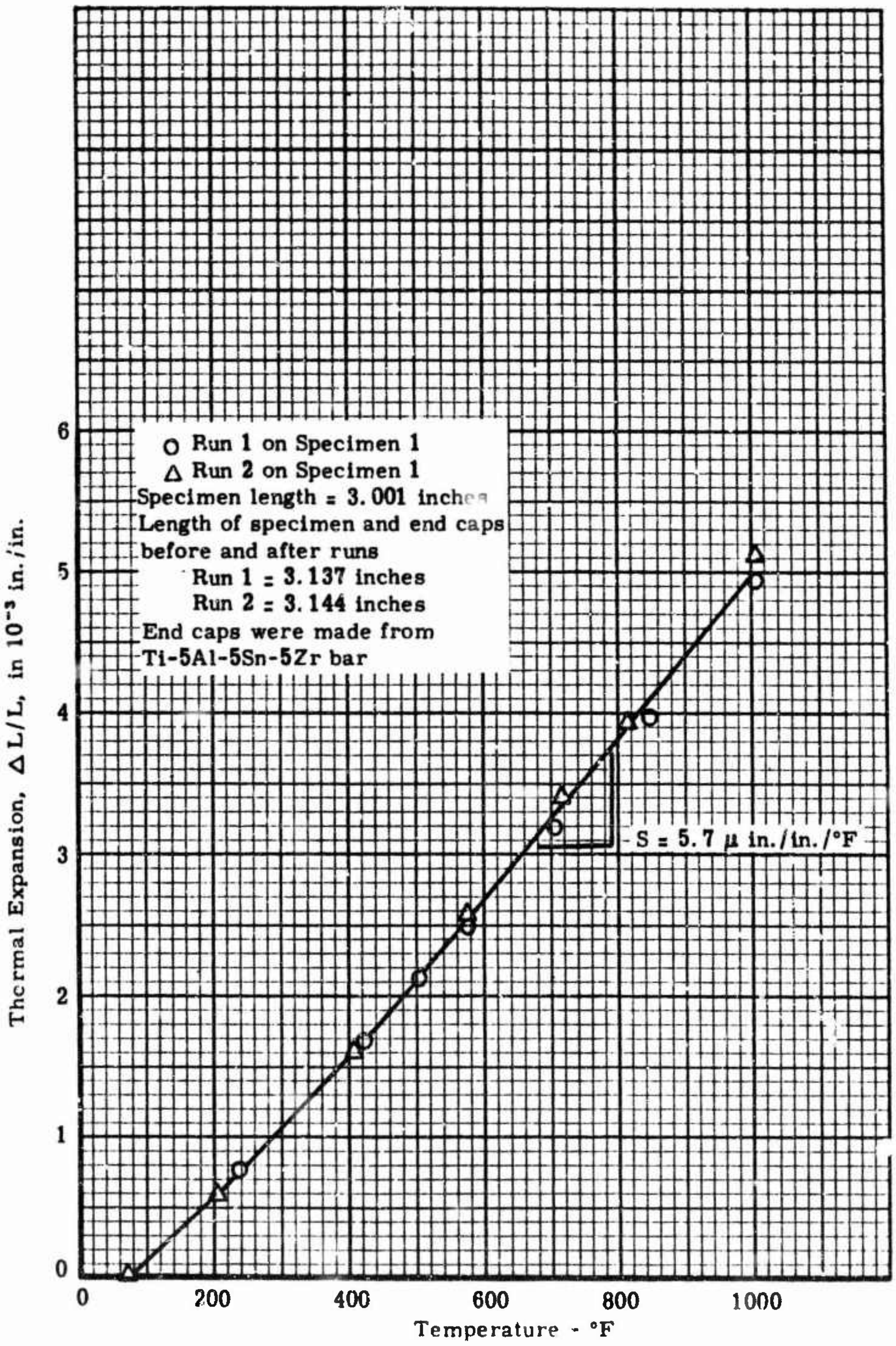


Figure 155. The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr-1Mo-1V in Sheet Form Transverse to the Rolling Direction.

Heat No. V-2957
Sheet thickness: 40 mil
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

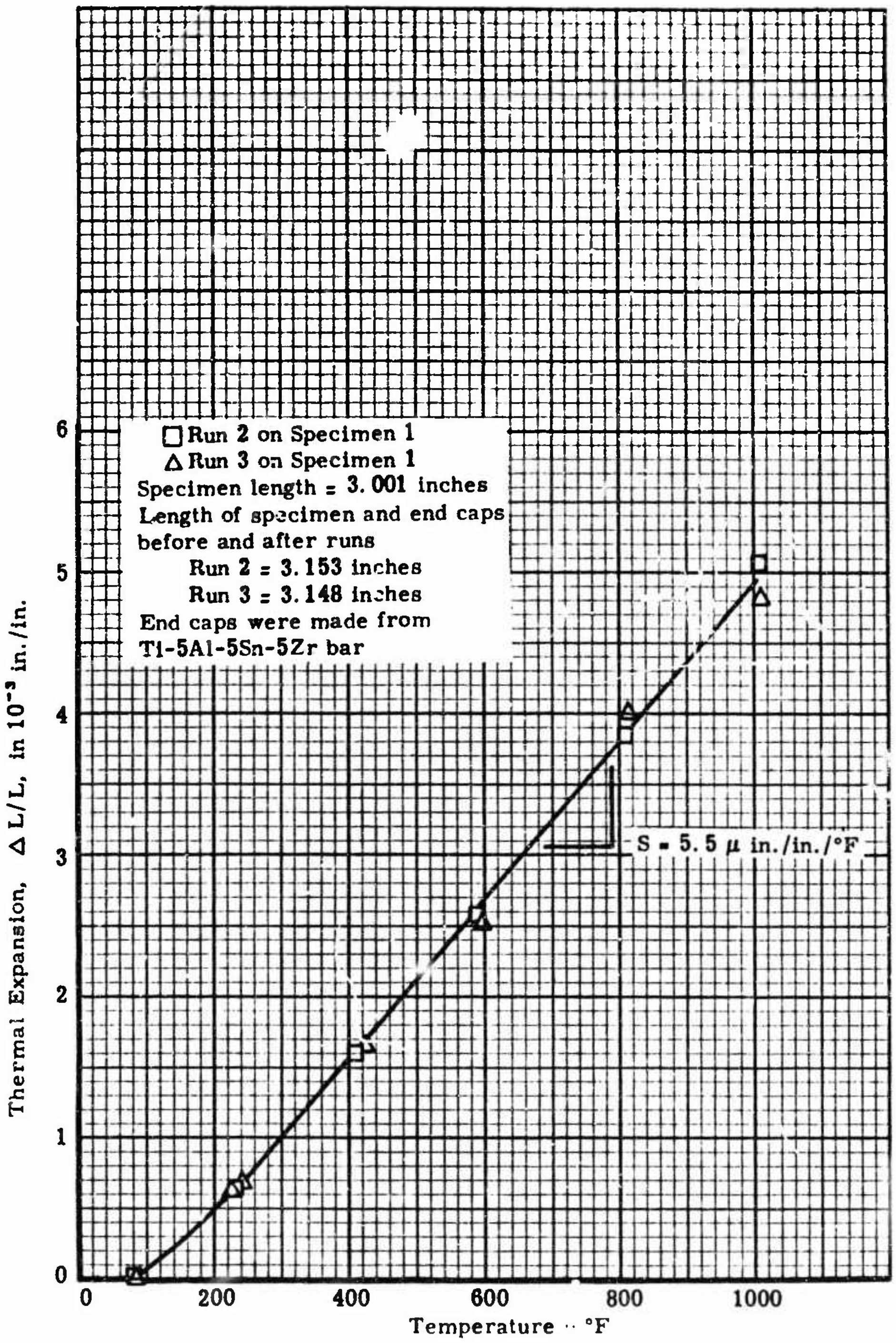


Figure 156. The Thermal Expansion of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form Parallel to the Rolling Direction.

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

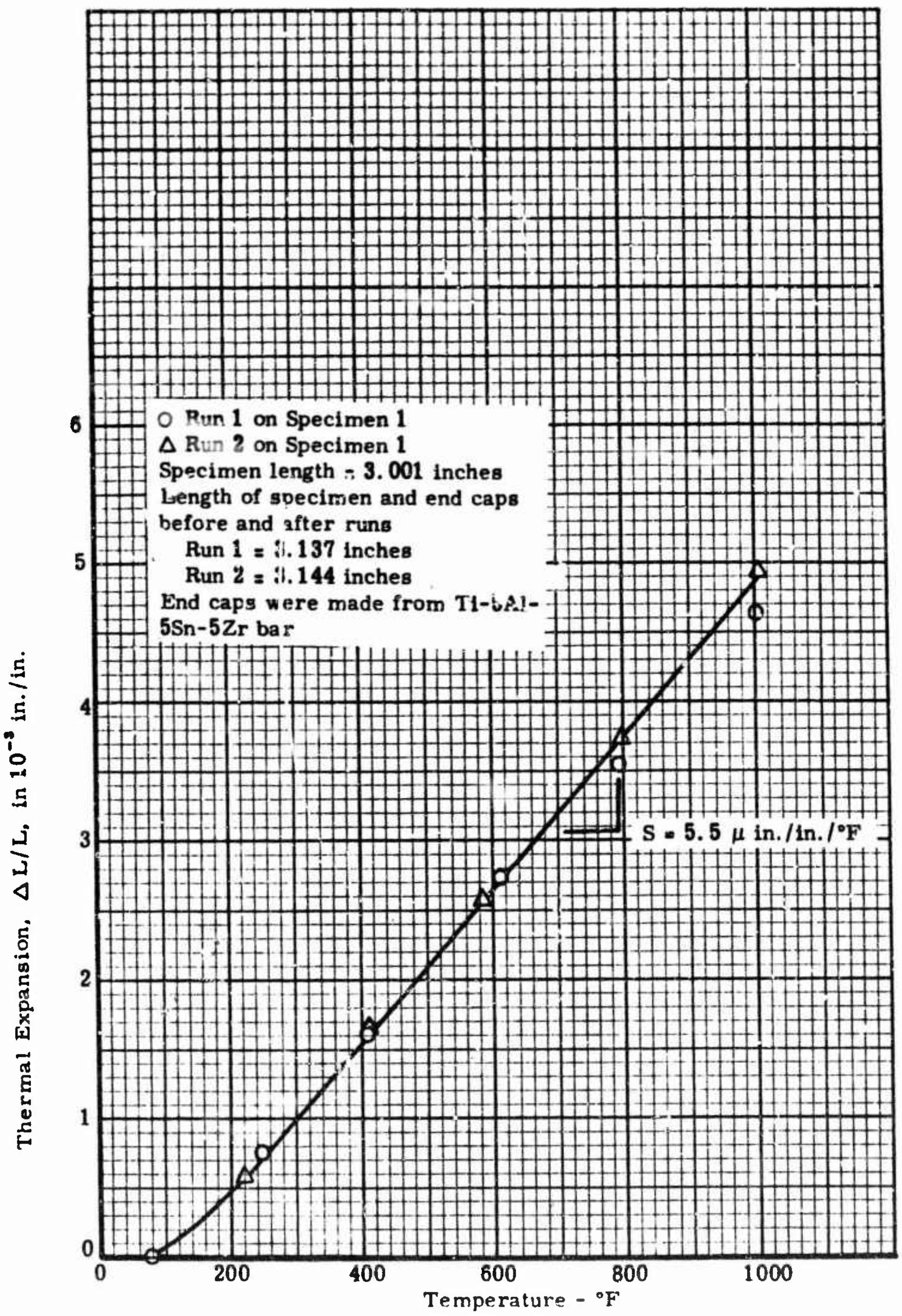


Figure 157. The Thermal Expansion of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form Transverse to the Rolling Direction.

Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

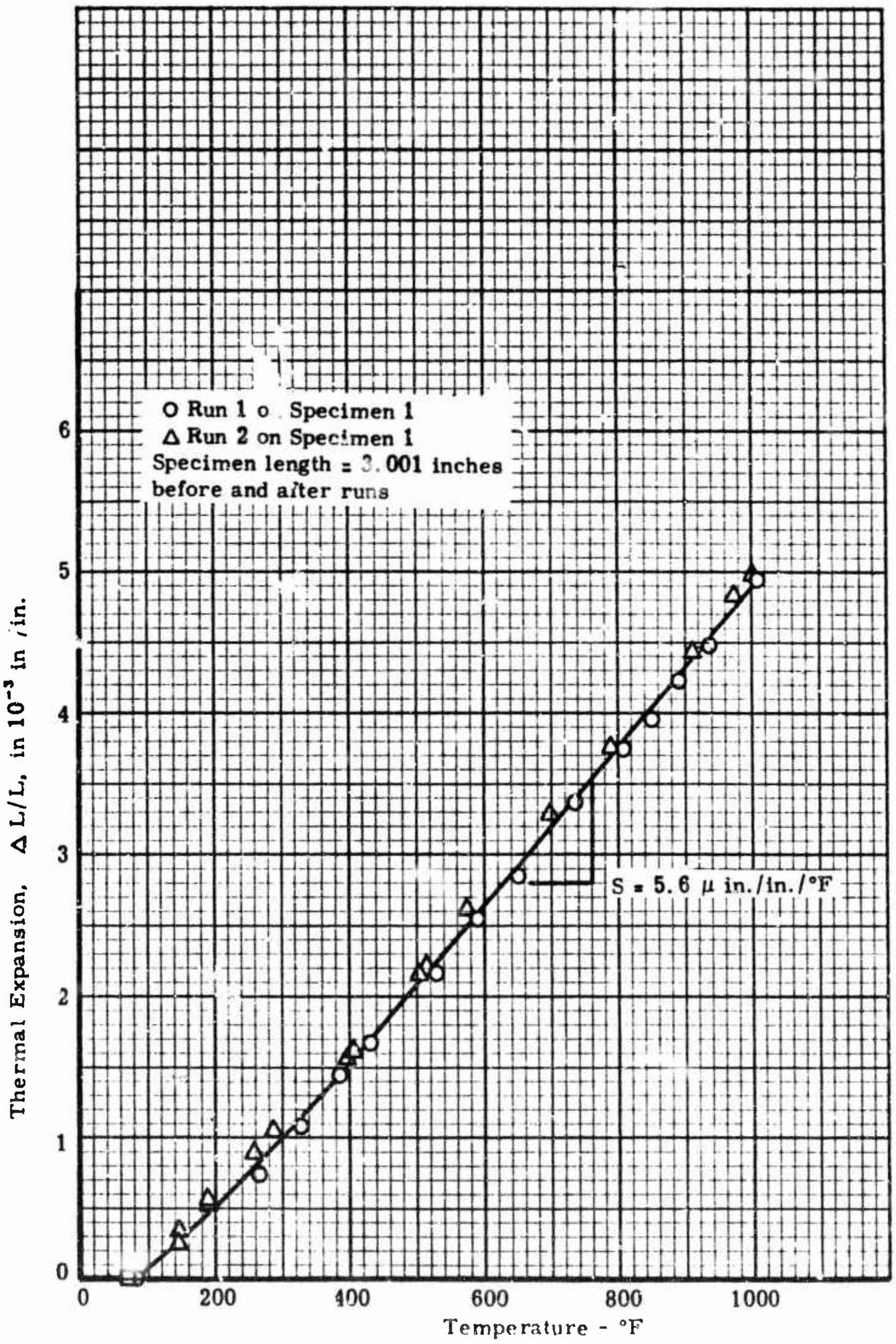


Figure 158. The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Bar Form Parallel to the Rolling Direction.

Heat No. D-8060
Section size: 1/2 in. x 1-1/8 in.
Heat treatment: 1650° F, 2 hr, A.C.

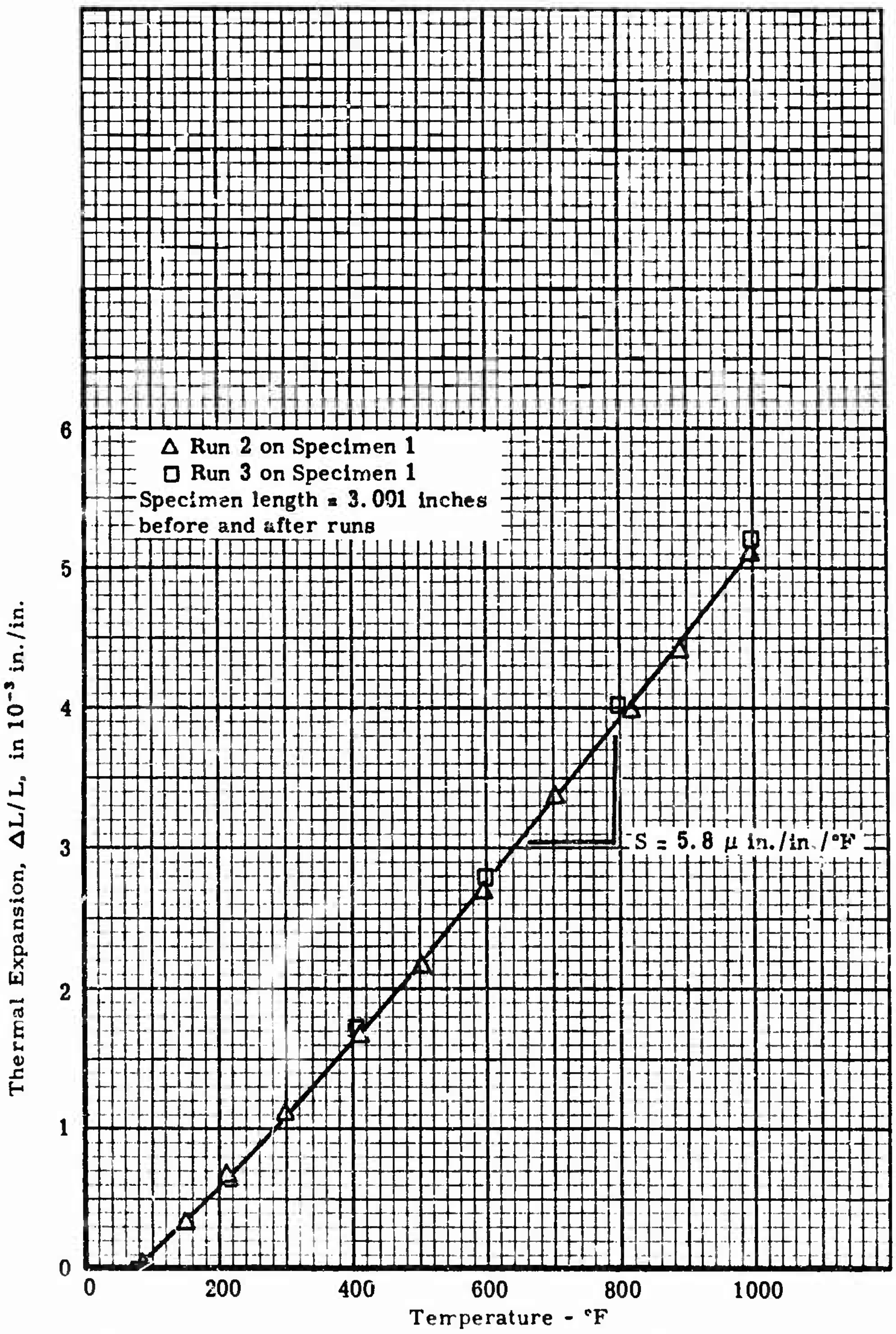


Figure 159. The Thermal Expansion of the Titanium Alloy Ti-679 in Bar Form Parallel to the Rolling Direction.

Heat No. D-7274
Section size: 1/2 in. x 1-1/2 in.
Heat treatment: 1350° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

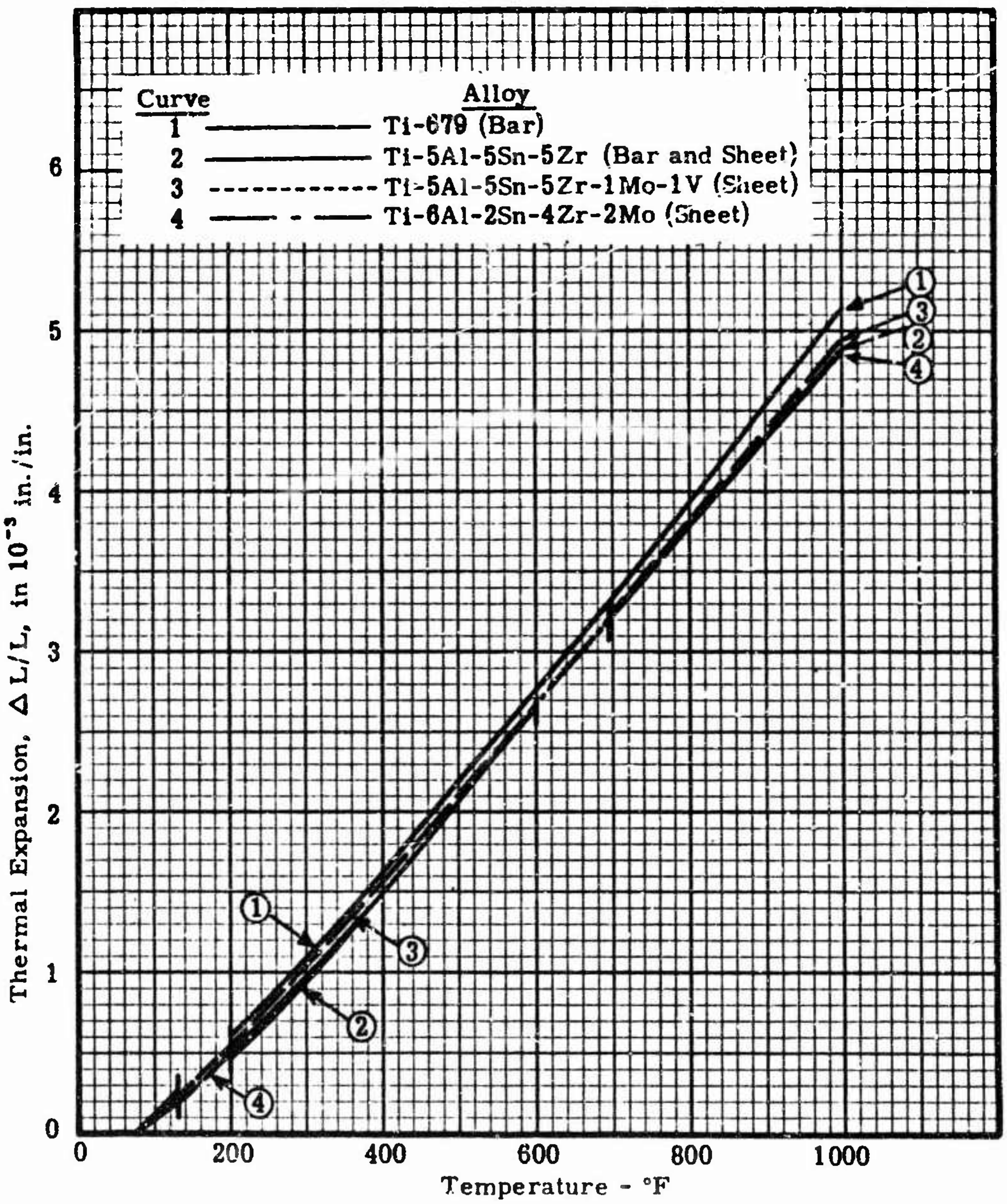


Figure 160. The Thermal Expansions of Four Titanium Alloys.

Specific Heat

The enthalpies and heat capacities of the four alloys are given in Figures 161 through 164 and the data are given in Tables 102 through 106 in Appendix II. A composite plot of the heat capacities is given in Figure 165. The heat capacities of the four alloys ranged from about 0.12 to 0.13 Btu/lb/° F from 100° F to 500° F, increasing slightly above 500° F. At 1000° F the heat capacity of the Ti-679, Ti-5Al-5Sn-5Zr, and Ti-5Al-5Sn-5Zr-1Mo-1V ranged from 0.14 to 0.15 Btu/lb/° F and the heat capacity of the Ti-5Al-2Sn-4Zr-2Mo was about 0.17 Btu/lb/° F.

The heat capacities at room temperature for the four alloys as calculated from heat capacities and the weight percentages of the alloying elements agreed well with the measured values. The calculated heat capacities were as follows: Ti-679, 0.115 Btu/lb/° F; Ti-5Al-5Sn-5Zr, 0.122 Btu/lb/° F; Ti-5Al-5Sn-5Zr-1Mo-1V, 0.122 Btu/lb/° F; Ti-6Al-2Sn-4Zr-2Mo, 0.125 Btu/lb/° F. These values all fall in the range of measured heat capacities from 0.12 to 0.13 Btu/lb/° F.

The enthalpy and heat capacity curves shown represent the best fit of the data by the graphical and least squares methods. The equations for the four alloys are given below.

1. Alloy: Ti-679

$$h_{85} = 117 \times 10^{-3}T + 71.3 \times 10^{-7}T^2 + 30.8 \times 10^2T^{-1} - 71.8$$
$$HC = 117 \times 10^{-3} + 142.6 \times 10^{-7}T - 22.9 \times 10^2T^{-2}$$

2. Alloy: Ti-5Al-5Sn-5Zr

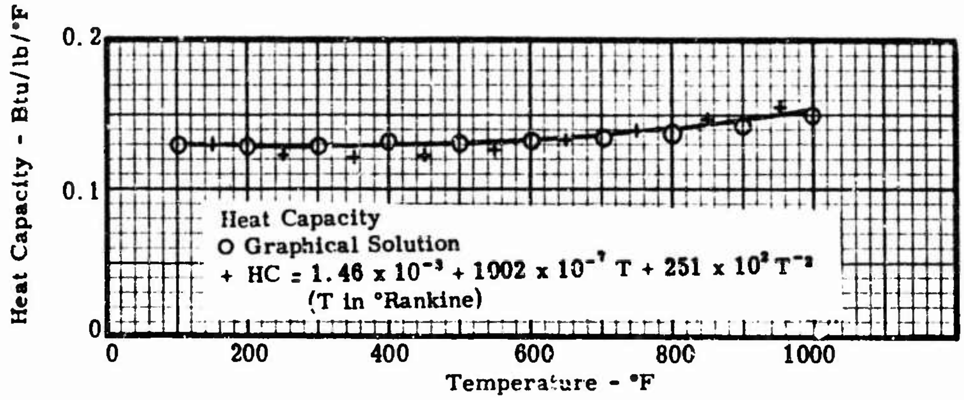
$$h_{85} = 1.46 \times 10^{-3}T + 501 \times 10^{-7}T^2 - 285 \times 10^2T^{-1} + 36.4$$
$$HC = 1.46 \times 10^{-3} + 1002 \times 10^{-7}T + 251 \times 10^2T^{-2}$$

3. Alloy: Ti-5Al-5Sn-5Zr-1Mo-1V

$$h_{85} = -71.8 \times 10^{-3}T + 732 \times 10^{-7}T^2 - 488 \times 10^2T^{-1} + 107$$
$$HC = -71.8 \times 10^{-3} + 1464 \times 10^{-7}T + 426 \times 10^2T^{-2}$$

4. Alloy: Ti-6Al-2Sn-4Zr-2Mo

$$h_{85} = -143 \times 10^{-3}T + 1078 \times 10^{-7}T^2 - 575 \times 10^2T^{-1} + 151$$
$$HC = -143 \times 10^{-3} + 2156 \times 10^{-7}T + 519 \times 10^2T^{-2}$$



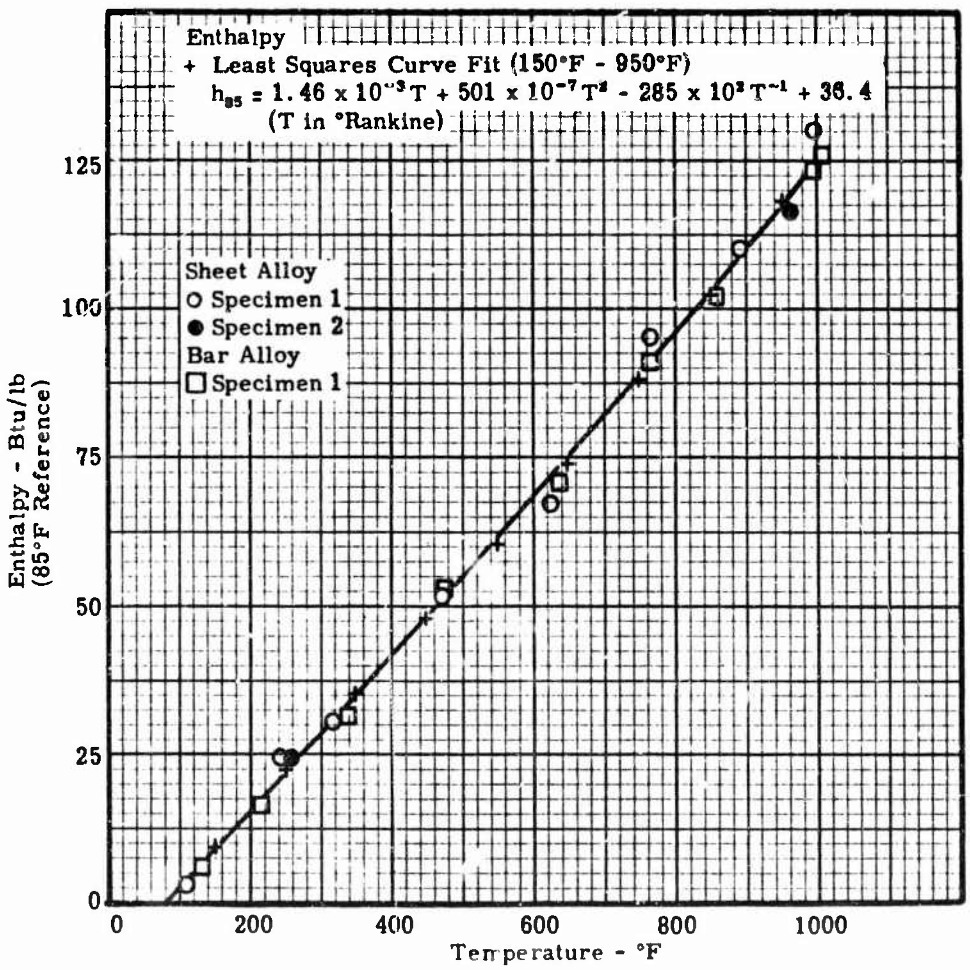


Figure 161. The Enthalpy and Heat Capacity of the Titanium Alloy Ti-5Al-5Sn-5Zr in Bar and Sheet Form

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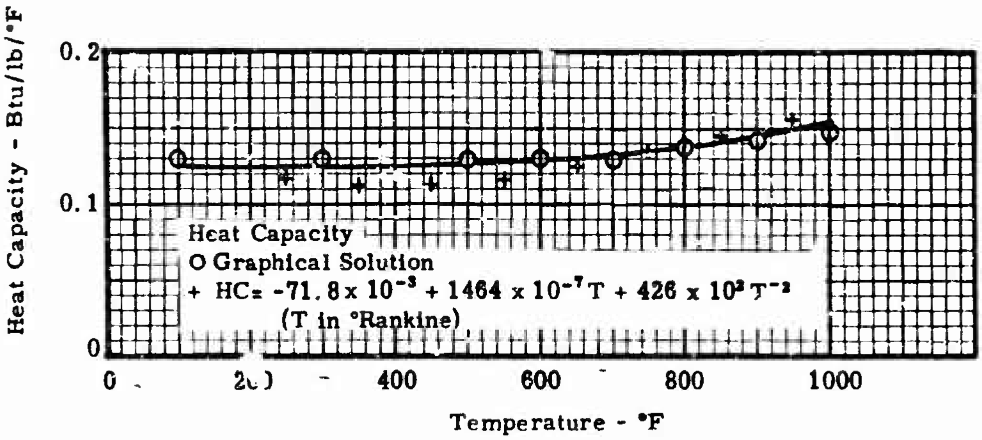
Heat No. D-8060
Bar Section: 1/2 in. x 1-1/2 in.
Sheet thickness: 40 mil
Heat treatment:
Sheet - 1650° F, 1/2 hr, A.C.
Bar - 1650° F, 2 hr, A.C.



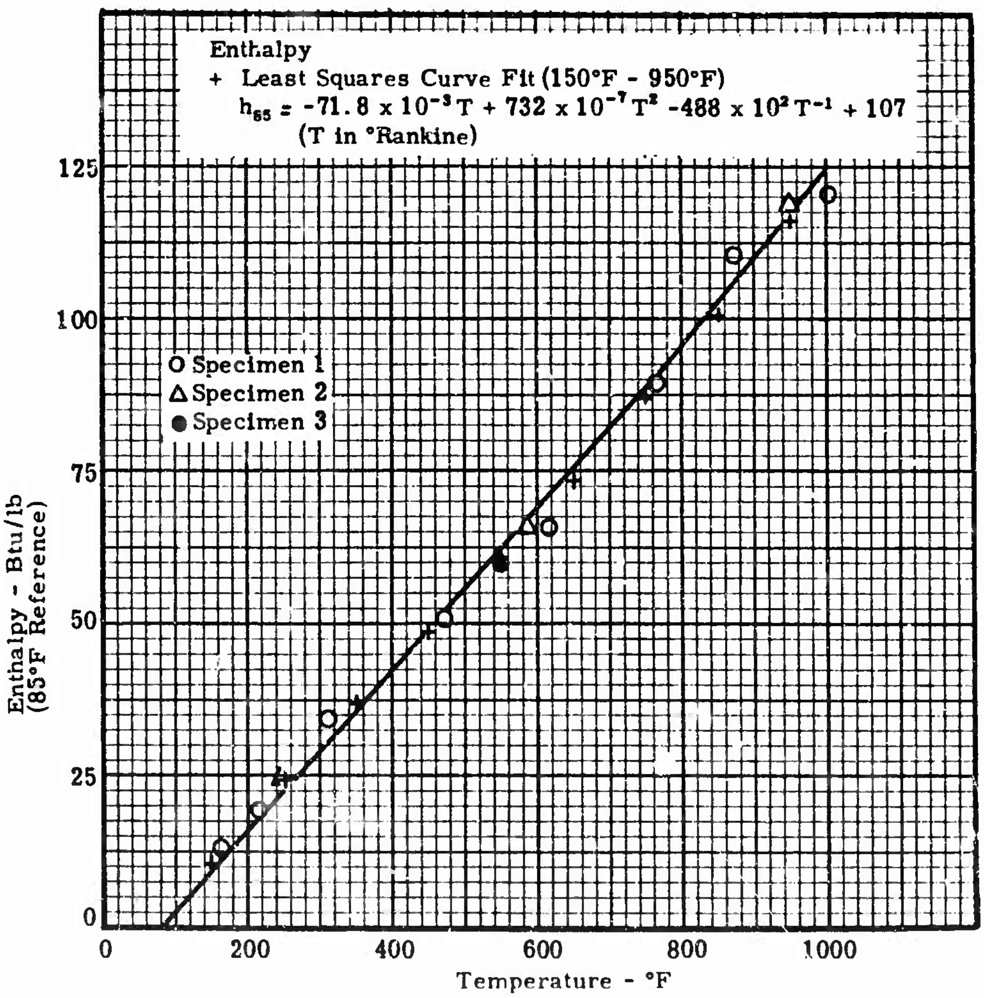


Figure 162. The Enthalpy and Heat Capacity of the Titanium Alloy Ti-5Al-5Sn-5Zr-1Mo-1V in Sheet Form

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Heat No. V-2957
Sheet thickness: 40 mils
Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

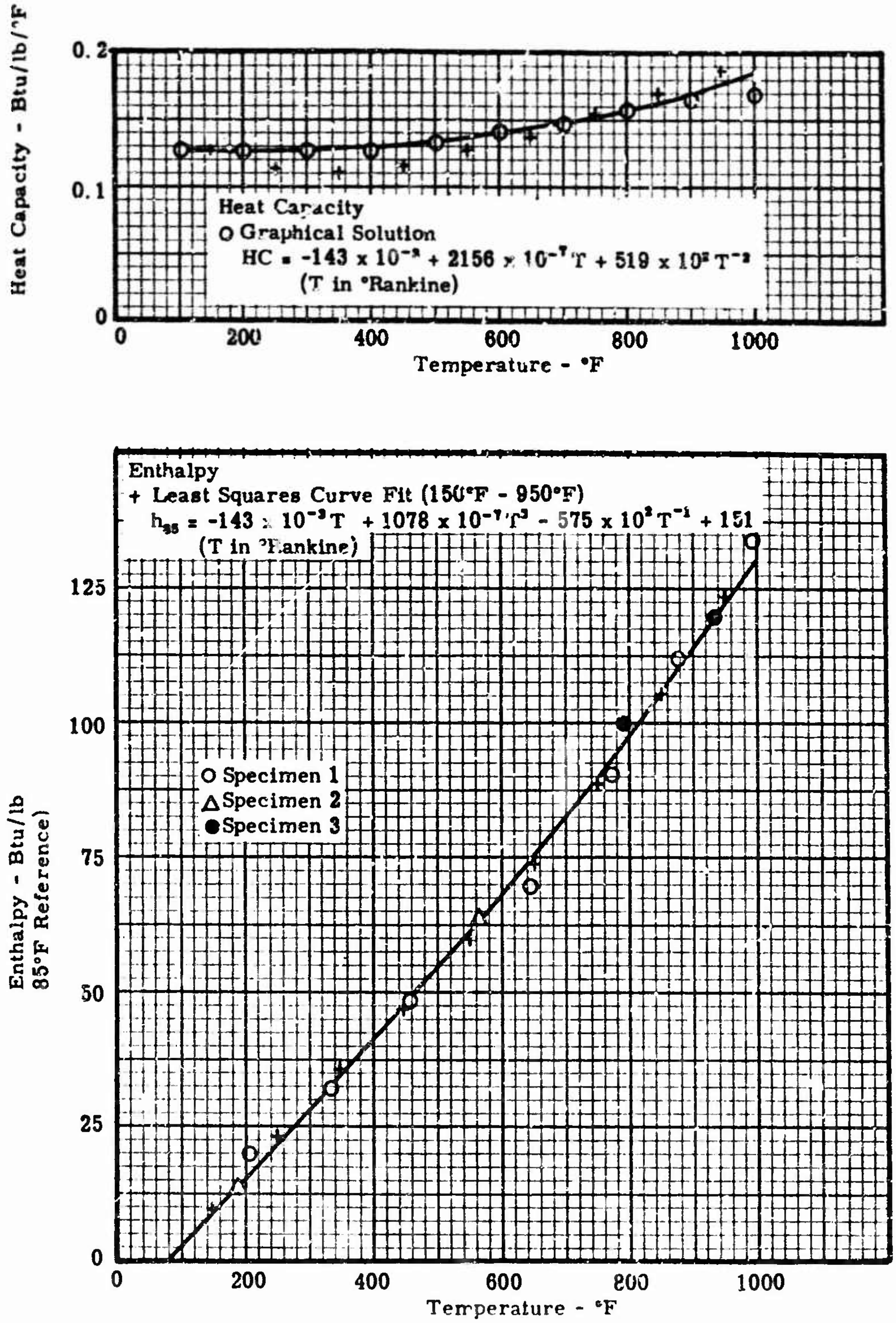

Figure 163. The Enthalpy and Heat Capacity of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form

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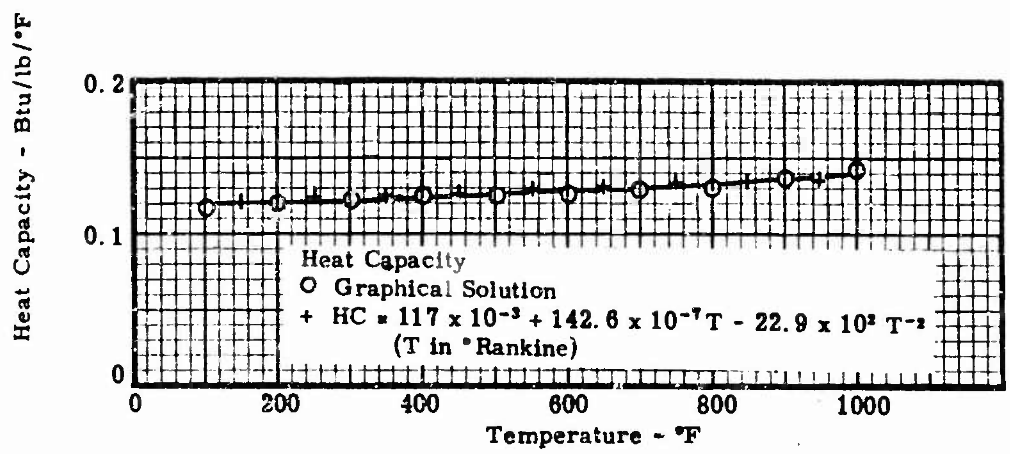
Heat No. V-3016
Sheet thickness: 40 mil
Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.



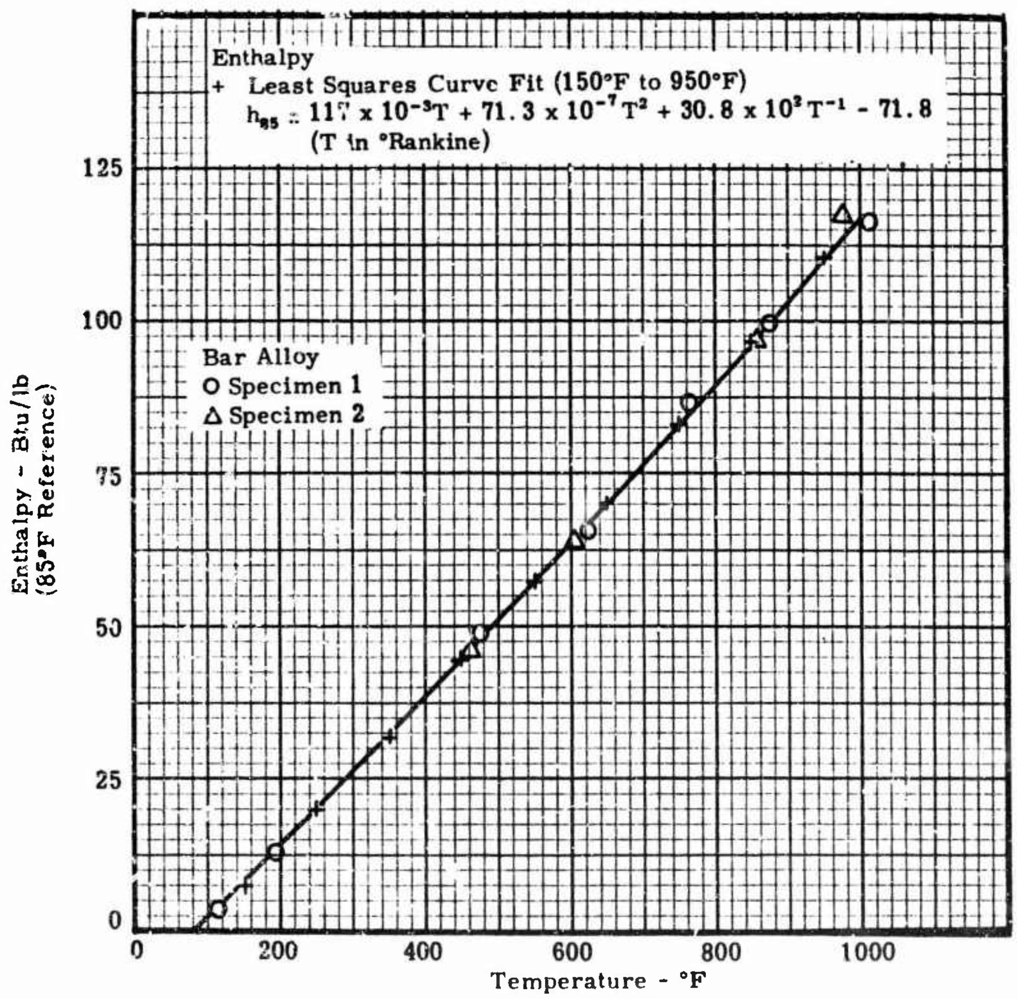


Figure 164. The Enthalpy and Heat Capacity of the Titanium Alloy Ti-679 in Bar Form

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Heat No. D-7274
Section size: 1/2 in. x 1-1/2 in.
Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

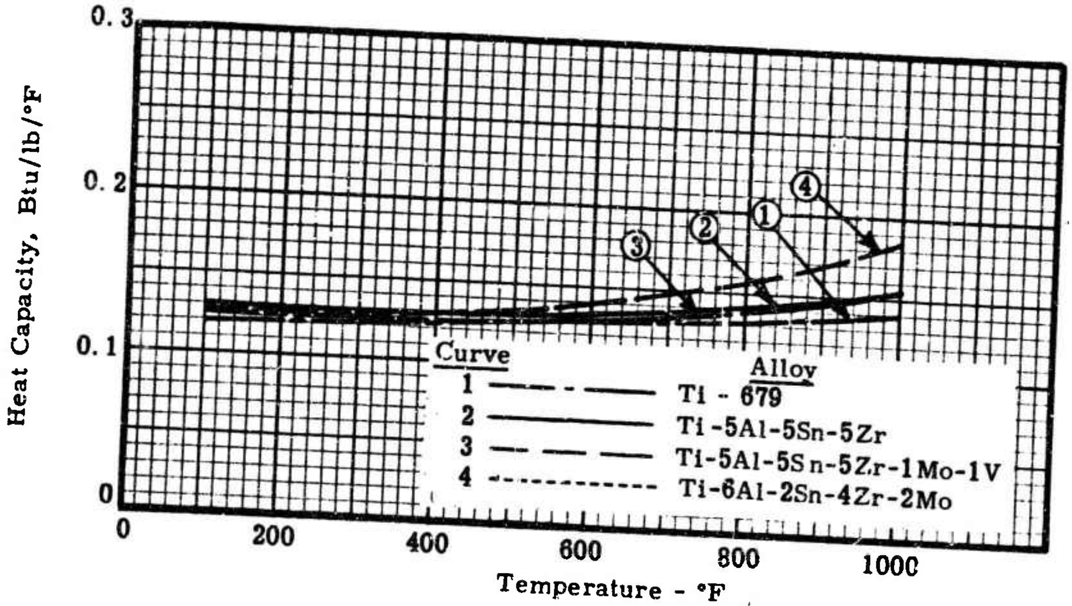

Figure 165. The Heat Capacities of Four Titanium Alloys

The temperatures (T) in these equations are in degrees Rankine, and the equations are limited to a temperature range from about 150° F to about 900° F. The enthalpies and heat capacities calculated using these equations are also plotted in Figures 161 through 164 at several temperatures.

CONCLUSIONS

The data developed in this investigation were analyzed by the normal statistical techniques used to establish mechanical-property design allowables for MIL-HDBK 5[6] and the results of these computations are given in tables 32 - 35 for the different alloys. It is recognized that the numbers of tests and heats upon which these computations are based is not sufficient for inclusion of these data sheets in MIL-HDBK 5 and these values may change as additional data become available. These values are intended to serve as a means for comparing these alloys with competitive alloys presently in MIL-HDBK 5 on the most realistic basis possible.

In all of the mechanical strength properties for which data are given in Tables 32 - 35, the strength of the alpha-beta sheet alloys (Ti-5Al-5Sn-5Zr-1Mo-1V and Ti-6Al-2Sn-4Zr-2Mo) are, as expected, higher than those of the all-alpha alloy (Ti-5Al-5Sn-5Zr). The derived design allowable for the ultimate bearing strength at e/D = 1.5 of the Ti-5Al-5Sn-5Zr alloy sheet is, however, comparable to the two alpha-beta alloys. In general, the apparent design allowables of the Ti-5Al-5Sn-5Zr-1Mo-1V sheet were slightly higher than those of the Ti-6Al-2Sn-4Zr-2Mo.

Among the other properties not included in Tables 32 - 35 for which significant differences in the sheet were noted were creep, axial fatigue, and stress corrosion. The all-alpha alloy sheet, Ti-5Al-5Sn-5Zr, had superior creep strength to the two alpha-beta alloys. However, the creep strength of the Ti-6Al-2Sn-4Zr-2Mo alloy was high relative to the Ti-5Al-5Sn-5Zr-1Mo-1V alloy. The fatigue strength of the Ti-6Al-2Sn-4Zr-2Mo alloy was, in general, slightly higher than for the other alloys. In stress-corrosion the preliminary tests indicated that the susceptibility temperature for stress-corrosion of the Ti-5Al-5Sn-5Zr alloy (600° F) was about 100° F higher than for the alpha-beta alloys (500° F). However, results of residual tensile tests on the sheet alloys showed that the tensile strength properties of the Ti-5Al-5Sn-5Zr alloys were depreciated to a greater extent by stress-corrosion exposure than were the properties of the alpha-beta alloys.

Of the bar alloys, the Ti-679 alpha-beta alloy had generally higher properties, as shown in Tables 32 and 35, than the Ti-5Al-5Sn-5Zr bar. However, at high temperatures the creep strength of the Ti-5Al-5Sn-5Zr bar was higher than that of the Ti-679 alloy.

There were no significant differences in the thermal properties (thermal conductivity, thermal expansion, and specific heat) of the four titanium alloys evaluated.

Table 32

Design Mechanical and Physical Properties for Ti-5Al-5Sn-5Zr

Form		Sheet and bar			
Condition		Solution annealed[a]			
Thickness or dia, in.		0.040		1/2 x 1-1/8	
Basis		A[b]	B[b]	A[b]	B[b]
Mechanical properties:					
F_{tu}, ksi	L	124	125	122	124
	T	122	123		
F_{ty}, ksi	L	115	116	116	117
	T	115	116		
F_{cy}, ksi	L	110	111	117	119
	T	115	116		
F_{su}, ksi	L	84	85	86	87
	T	90	91		
F_{bru}, ksi (e/D = 1.5)	L	188	189		
	T	201	203		
(e/D = 2.0)	L	200	202		
	T	214	216		
F_{bry}, ksi (e/D = 1.5)	L	148	149		
	T	164	165		
(e/D = 2.0)	L	169	171		
	T	192	194		
e, per cent In 2 in.	L	12		13	
	T	14			
E, 10^6 psi		16.1			
E_c, 10^6 psi		15.0			
Physical properties:					
C, Btu/(lb) (° F)		0.12 between 100 - 500° F			
K, Btu/[(hr)(ft²)(° F)/ft]		4.6 at 100° F			
α, 10^{-6} in./in./° F		5.6 between 200 and 1000° F			

a Heat treatment: Sheet, 1650° F, 1/2 hr, A.C.
Bar, 1650° F, 2 hr, A.C.

b Tentative A and B values not approved for MIL-HDBK-5. For comparison purposes only.

Table 33

Design Mechanical and Physical Properties for Ti-5Al-5Sn-5Zr-1Mo-1V

Form		Sheet		
Condition		Solution-annealed and hot-sized[a]		
Thickness or dia, in.		0.040		
Basis		A[b]	B[b]	
Mechanical properties:				
F_{tu}, ksi	L	143	145	
	T	141	144	
F_{ty}, ksi	L	132	134	
	T	132	134	
F_{cy}, ksi	L	131	133	
	T	136	141	
F_{su}, ksi	L	102	103	
	T	104	106	
F_{bru}, ksi (e/D = 1.5)	L	208	211	
	T	213	216	
(e/D = 2.0)	L	198	202	
	T	249	254	
F_{bry}, ksi (e/D = 1.5)	L	186	192	
	T	180	184	
(e/D = 2.0)	L	143	146	
		210	214	
e, per cent In 2 in.	L	9		
	T	8		
E, 10^6 psi		15.0		
E_c, 10^6 psi		14.8		
Physical properties:				
C, Btu/(lb)(°F)		0.12 between 100 and 500° F		
K, Btu/[(hr)(ft²)(°F)/ft]		4.3 at 100° F		
α, 10^{-6} in./in./°F		5.7 between 200 and 1000° F		

a Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

b Tentative A and B values not approved for MIL-HDBK-5. For comparison purposes only.

Table 34

Design Mechanical and Physical Properties for Ti-6Al-2Sn-4Zr-2Mo

Form		Sheet	
Condition		Solution-annealed and hot-sized[a]	
Thickness or dia, in.		0.040	
Basis		A[b]	B[b]
Mechanical properties:			
F_{tu}, ksi	L	139	143
	T	140	142
F_{ty}, ksi	L	134	137
	T	133	135
F_{cy}, ksi	L	127	130
	T	117	132
F_{su}, ksi	L	85	87
	T	85	87
F_{bru}, ksi (e/D = 1.5)	L	193	200
	T	192	195
(e/D = 2.0)	L	253	262
	T	225	229
F_{bry}, ksi (e/D = 1.5)	L	174	178
	T	148	150
(e/D = 2.0)	L	201	206
	T	206	209
e, per cent In 2 in.	L	8	
	T	6	
E, 10^6 psi		16.1	
E_c, 10^6 psi		14.4	
Physical properties:			
C, Btu/(lb)(°F)		0.12 between 100 and 500° F	
K, Btu/[(hr)(ft²)(°F)/ft]		4.7 at 100° F	
α, 10^{-6} in./in./°F		5.5 between 200 and 1000° F	

a Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.
b Tentative A and B values not approved for MIL-HDBK-5. For comparison purposes only.

Table 35

Design Mechanical and Physical Properties for Ti-679[a]

Form	Bar		
Condition	Solution-annealed and aged[b]		
Thickness or dia, in.	1/2 x 1-1/8		
Basis	A[c]	B[c]	
Mechanical properties:			
F_{tu}, ksi			
L	140	142	
F_{ty}, ksi			
L	128	133	
F_{cy}, ksi			
L	124	129	
F_{su}, ksi			
L	88	89	
e, per cent			
In 2 in.	12		
E, 10^6 psi	15.2		
E_c, 10^6 psi	14.5		
Physical properties:			
C, Btu/(lb)(°F)	0.12 between 100 and 500° F		
K, Btu/[(hr)(ft²)(°F)/ft]	4.7 at 100° F		
α, 10^{-6} in./in./°F	5/9 between 200 and 1000° F		

a Nominal composition: 2-1/4% Al, 11% Sn, 5% Zr, 1% Mo, 0.20% Si
b Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.
c Tentative A and B values not approved for MIL-HDBK-5. For comparison purposes only.

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APPENDIX I

Mechanical Property Test Data

(Tables No. 36 - 88)

Table 36

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Sheet from Heat No. D-8060 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
5A-1L	70	L	120.1	127.7	14	16.4
5A-6L	70	L	118.8	128.7	12	16.0
5A-11L	70	L	116.3	127.0	14	15.5
5A-16L	70	L	118.2	127.9	14	16.0
5A-21L	70	L	118.7	128.6	14	15.7
5A-26L	70	L	119.1	129.5	14	16.3
5A-31L	70	L	118.5	128.6	16	17.3
5A-36L	70	L	118.0	128.4	14	15.7
5A-41L	70	L	119.0	129.4	15	15.6
5A-46L	70	L	118.8	128.8	14	16.2
5A-1T	70	T	119.4	127.3	14	16.7
5A-6T	70	T	119.4	127.3	14	16.4
5A-11T	70	T	118.5	128.2	15	16.5
5A-16T	70	T	118.3	126.3	15	16.4
5A-21T	70	T	118.0	126.3	16	16.9
5A-26T	70	T	118.5	126.7	15	16.3
5A-31T	70	T	117.9	126.4	15	16.7
5A-36T	70	T	117.0	125.9	15	16.4
5A-41T	70	T	119.0	127.1	15	17.0
5A-46T	70	T	118.5	127.4	15	16.6
5A-2L	400	L	80.6	98.3	17	15.2
5A-7L	400	L	79.7	97.7	18	12.5
5A-12L	400	L	78.7	96.7	18	13.9
5A-17L	400	L	79.3	97.8	20	13.9
5A-22L	400	L	79.0	98.0	19	14.1
5A-27L	400	L	78.9	97.9	18	13.5
5A-32L	400	L	78.7	97.0	18	14.1
5A-37L	400	L	79.6	96.8	19	14.1
5A-42L	400	L	78.9	97.4	19	14.1
5A-47L	400	L	78.9	97.4	18	13.4
5A-2T	400	T	78.8	93.8	20	13.4
5A-7T	400	T	79.4	93.9	21	13.7
5A-12T	400	T	77.9	92.8	20	15.0
5A-17T	400	T	78.5	93.3	20	13.3
5A-22T	400	T	79.3	93.7	19	13.0
5A-27T	400	T	78.5	93.3	20	14.0
5A-32T	400	T	78.4	93.9	21	17.3
5A-37T	400	T	79.3	93.3	20	13.8
5A-42T	400	T	77.7	92.7	21	16.0
5A-47T	400	T	78.2	93.6	20	14.3

Table 36 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
5A-3L	600	L	67.7	91.0	18	11.9
5A-8L	600	L	66.4	89.3	18	12.6
5A-13L	600	L	65.0	88.2	17	11.6
5A-18L	600	L	66.0	89.0	17	12.4
5A-23L	600	L	66.4	89.7	19	11.4
5A-28L	600	L	66.0	89.2	21	10.4
5A-33L	600	L	66.0	89.8	19	14.9
5A-38L	600	L	66.3	89.6	20	12.4
5A-43L	600	L	66.4	90.0	18	12.4
5A-48L	600	L	66.5	89.9	17	12.2
5A-3T	600	T	65.5	84.3	21	13.1
5A-8T	600	T	65.7	85.5	19	13.7
5A-13T	600	T	65.2	84.6	22	14.0
5A-18T	600	T	66.0	85.0	20	14.0
5A-23T	600	T	65.7	85.5	20	12.9
5A-28T	600	T	65.8	85.5	20	15.0
5A-33T	600	T	65.0	84.6	21	11.4
5A-38T	600	T	64.6	84.3	20	15.2
5A-43T	600	T	65.4	84.5	18	13.2
5A-48T	600	T	65.7	85.8	21	12.9
5A-4L	800	L	67.2	85.3	24	15.4
5A-9L	800	L	59.7	81.2	22	12.8
5A-14L	800	L	59.5	82.7	24	12.4
5A-19L	800	L	60.6	83.8	22	10.1
5A-24L	800	L	60.7	84.0	23	11.8
5A-29L	800	L	60.6	84.4	25	11.5
5A-34L	800	L	60.4	83.5	24	11.1
5A-39L	800	L	59.8	82.8	25	12.9
5A-44L	800	L	60.8	83.6	22	11.0
5A-49L	800	L	61.7	83.8	20	12.4
5A-4T	800	T	59.8	79.0	24	14.8
5A-9T	800	T	60.8	79.7	27	11.5
5A-14T	800	T	58.8	78.7	30	12.2
5A-19T	800	T	60.2	78.7	26	14.2
5A-24T	800	T	59.6	79.4	29	11.3
5A-29T	800	T	59.3	78.4	28	13.5
5A-54T	800	T	60.7	81.0	29	12.6
5A-56T	800	T	60.8	80.7	25	13.9
5A-44T	800	T	59.7	80.2	25	12.5
5A-49T	800	T	61.0	79.8	23	11.5

Table 36 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
5A-5L	1000	L	60.0	80.0	21	11.1
5A-10L	1000	L	58.0	79.7	23	13.2
5A-15L	1000	L	58.2	78.7	22	10.5
5A-20L	1000	L	60.6	80.6	22	10.4
5A-25L	1000	L	60.2	80.4	19	10.2
5A-30L	1000	L	57.8	78.8	21	9.8
5A-174L	1000	L	60.0	80.3	21	13.0
5A-40L	1000	L	58.6	78.6	21	10.2
5A-45L	1000	L	58.6	78.7	22	11.0
5A-50L	1000	L	58.0	78.4	20	11.1
5A-5T	1000	T	57.9	74.6	26	12.2
5A-10T	1000	T	58.6	75.4	25	11.1
5A-15T	1000	T	57.2	74.6	25	11.3
5A-20T	1000	T	58.2	75.6	25	13.3
5A-25T	1000	T	57.8	76.4	24	12.3
5A-30T	1000	T	57.6	75.0	25	11.4
5A-35T	1000	T	57.4	74.5	24	12.2
5A-40T	1000	T	57.8	74.7	23	11.1
5A-45T	1000	T	58.2	75.3	23	12.5
5A-50T	1000	T	58.2	74.4	23	11.1

[a] Thickness: 40 mils
[b] Heat treatment: 1650°F, 1/2 hr, A.C.

Table 37

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Sheet from Heat No. D-1793 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	Fty ksi	Ftu ksi	e %	E_t 10^6 psi
5B-1L	70	L	115.6	123.9	18	14.4
5B-6L	70	L	115.3	124.3	17	14.1
5B-11L	70	L	116.6	124.5	17	16.1
5B-16L	70	L	117.2	126.1	19	15.3
5B-21L	70	L	117.0	124.6	18	15.0
5B-26L	70	L	118.9	124.3	16	15.2
5B-31L	70	L	115.5	124.6	17	15.5
5B-36L	70	L	117.0	124.5	18	15.9
5B-41L	70	L	116.3	124.6	18	15.6
5B-46L	70	L	115.2	123.8	16	15.4
5B-1T	70	T	116.5	122.8	18	16.1
5B-6T	70	T	115.4	122.5	18	16.2
5B-11T	70	T	116.2	122.5	19	14.8
5B-16T	70	T	115.1	122.3	18	15.3
5B-21T	70	T	114.8	121.6	18	14.9
5B-26T	70	T	115.8	122.6	18	15.8
5B-31T	70	T	115.8	122.4	18	15.9
5B-36T	70	T	115.5	121.8	17	15.4
5B-41T	70	T	114.4	120.6	17	15.2
5B-46T	70	T	115.0	121.8	18	15.0
5B-2L	400	L	78.1	96.3	17	12.8
5B-7L	400	L	78.2	96.4	18	12.5
5B-12L	400	L	82.0	98.5	17	17.5
5B-17L	400	L	81.0	97.7	19	13.9
5B-22L	400	L	79.5	95.8	19	13.6
5B-27L	400	L	80.2	96.8	19	13.2
5B-32L	400	L	84.8	94.8	19	13.0
5B-37L	400	L	83.7	98.6	18	13.9
5B-42L	400	L	79.4	96.3	18	14.7
5B-47L	400	L	81.4	97.7	19	12.5
5B-2T	400	T	80.6	93.6	20	14.1
5B-7T	400	T	80.9	93.9	20	12.8
5B-12T	400	T	80.7	93.8	20	13.4
5B-17T	400	T	80.3	92.9	20	12.5
5B-22T	400	T	79.8	92.8	20	13.6
5B-27T	400	T	78.4	91.1	20	12.8
5B-32T	400	T	78.8	91.5	20	14.9
5B-37T	400	T	79.6	92.7	20	13.2
5B-47T	400	T	79.4	92.4	20	13.8
5B-57T	400	T	80.7	93.1	20	12.6

Table 37 (Continued)

Specimen No.	Temp., °F	Orientation	Fty ksi	Ftu ksi	e %	E_t 10^6 psi
5B-3L	600	L	68.4	91.2	24	13.4
5B-8L	600	L	67.9	90.4	25	13.0
5B-13L	600	L	68.6	91.0	22	12.9
5B-18L	600	L	68.6	91.4	25	15.1
5B-23L	600	L	68.1	90.0	21	13.2
5B-28L	600	L	69.0	91.8	23	12.4
5B-33L	600	L	68.4	90.8	25	11.4
5B-38L	600	L	68.0	91.7	25	12.8
5B-43L	600	L	68.1	90.7	24	11.8
5B-48L	600	L	68.1	91.2	24	13.0
5B-3T	600	T	67.8	86.4	21	13.9
5B-8T	600	T	68.0	87.3	27	13.5
5B-13T	600	T	67.4	86.6	25	13.3
5B-18T	600	T	67.4	86.6	26	13.6
5B-23T	600	T	67.5	85.9	25	13.5
5B-28T	600	T	68.9	87.0	24	14.4
5B-33T	600	T	68.6	86.2	24	13.8
5B-38T	600	T	69.0	86.4	23	14.1
5B-43T	600	T	68.4	86.9	25	13.0
5B-48T	600	T	66.3	84.3	25	13.3
5B-4L	800	L	64.2	84.7	25	12.1
5B-9L	800	L	63.4	85.4	23	11.6
5B-14L	800	L	62.4	84.7	22	12.4
5B-19L	800	L	62.3	83.5	23	13.0
5B-24L	800	L	62.0	83.6	24	12.6
5B-29L	800	L	62.1	84.6	23	12.7
5B-34L	800	L	63.3	84.9	23	11.3
5B-39L	800	L	61.7	85.4	24	12.1
5B-44L	800	L	61.0	84.7	23	11.5
5B-49L	800	L	64.0	85.7	24	12.0
5B-4T	800	T	62.3	81.7	25	14.5
5B-9T	800	T	63.2	81.7	25	12.3
5B-14T	800	T	63.1	81.6	26	14.4
5B-19T	800	T	62.7	81.4	27	13.3
5B-24T	800	T	63.5	81.5	27	13.3
5B-29T	800	T	62.4	81.4	27	14.6
5B-34T	800	T	62.8	81.7	26	12.7
5B-39T	800	T	62.9	81.2	27	13.8
5B-44T	800	T	61.1	80.9	28	12.7
5B-49T	800	T	60.8	79.7	26	12.4

Table 37 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
5B-5L	1000	L	62.3	82.8	22	11.6
5B-10L	1000	L	62.4	82.5	24	10.9
5B-15L	1000	L	62.7	83.0	24	10.5
5B-20L	1000	L	62.3	80.8	24	10.4
5B-25L	1000	L	61.4	81.3	23	10.2
5B-30L	1000	L	62.4	81.7	25	10.6
5B-35L	1000	L	62.2	82.0	24	10.1
5B-40L	1000	L	62.8	82.2	23	10.5
5B-45L	1000	L	62.5	82.3	23	10.7
5B-50L	1000	L	62.6	82.0	26	9.8
5B-5T	1000	T	61.3	78.3	25	11.8
5B-10T	1000	T	61.3	78.8	26	10.9
5B-15T	1000	T	61.3	73.0	26	10.8
5B-20T	1000	T	61.7	79.2	25	12.9
5B-25T	1000	T	63.4	77.8	25	11.3
5B-30T	1000	T	61.3	77.9	27	11.0
5B-35T	1000	T	61.7	78.2	24	10.5
5B-40T	1000	T	61.4	77.5	22	11.7
5B-45T	1000	T	61.2	78.2	26	10.4
5B-50T	1000	T	60.8	77.0	27	12.0

[a] Thickness: 40 mils.
[b] Heat treatment: 1650°F, 1/2 hr, A.C.

Table 38

Tensile Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet from Heat No. V-2957 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	Et 10^6 psi
1A-1L	70	L	137.5	148.1	11	15.0
1A-6L	70	L	135.3	146.6	11	14.5
1A-11L	70	L	136.3	145.4	10	14.5
1A-16L	70	L	137.1	146.5	11	14.6
1A-21L	70	L	138.1	145.4	12	14.5
1A-26L	70	L	137.9	149.0	10	14.5
1A-31L	70	L	135.2	146.6	10	14.5
1A-36L	70	L	136.2	146.5	11	14.5
1A-41L	70	L	136.1	146.1	11	14.4
1A-46L	70	L	138.3	148.1	11	14.5
1A-1T	70	T	138.4	146.4	8	15.5
1A-6T	70	T	137.8	147.1	10	16.0
1A-11T	70	T	140.5	147.6	11	16.0
1A-16T	70	T	138.2	145.9	11	15.7
1A-21T	70	T	140.0	148.0	10	14.5
1A-26T	70	T	137.5	148.0	10	16.3
1A-31T	70	T	136.4	147.4	12	15.8
1A-36T	70	T	139.2	146.8	10	15.7
1A-41T	70	T	136.2	147.1	11	15.9
1A-46T	70	T	134.9	146.4	11	16.2
1A-2L	400	L	105.3	123.3	10	13.4
1A-7L	400	L	106.8	124.5	11	13.1
1A-12L	400	L	105.5	123.1	10	14.3
1A-17L	400	L	104.8	120.4	9	12.8
1A-22L	400	L	105.2	122.5	10	13.4
1A-27L	400	L	108.5	125.4	10	12.5
1A-32L	400	L	106.9	124.1	9	13.3
1A-37L	400	L	106.5	123.1	10	13.3
1A-42L	400	L	104.1	121.0	10	12.6
1A-47L	400	L	106.3	123.1	10	13.1
1A-2T	400	T	111.3	123.8	8	13.4
1A-7T	400	T	108.3	121.8	9	14.0
1A-12T	400	T	108.9	120.7	9	13.6
1A-17T	400	T	108.4	121.5	9	14.8
1A-22T	400	T	107.2	119.6	8	14.7
1A-27T	400	T	111.1	122.9	8	14.3
1A-32T	400	T	111.0	123.9	8	13.9
1A-37T	400	T	107.8	119.6	8	13.6
1A-42T	400	T	110.6	123.5	9	13.1
1A-47T	400	T	111.2	123.3	9	14.0

Table 38 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
1A-3L	600	L	97.2	119.5	10	12.6
1A-8L	600	L	97.6	120.3	10	12.4
1A-13L	600	L	98.1	119.0	10	12.1
1A-18L	600	L	97.5	120.7	10	11.5
1A-23L	600	L	96.5	119.0	10	12.7
1A-176	600	L	98.4	121.5	10	12.5
1A-33L	600	L	98.2	121.5	11	12.1
1A-38L	600	L	97.9	119.5	10	11.7
1A-43L	600	L	97.3	120.2	9	13.1
1A-48L	600	L	97.8	121.1	10	12.0
1A-3T	600	T	100.7	117.4	8	13.0
1A-8T	600	T	101.0	117.7	8	13.5
1A-13T	600	T	100.0	116.9	9	13.8
1A-18T	600	T	101.5	117.6	8	12.6
1A-23T	600	T	100.2	117.5	9	13.1
1A-28T	600	T	103.1	118.9	8	14.1
1A-33T	600	T	103.0	119.1	8	13.9
1A-38T	600	T	101.2	117.7	8	13.8
1A-43T	600	T	101.5	118.5	8	12.9
1A-48T	600	T	102.5	117.7	8	13.0
1A-4L	800	L	91.7	119.4	13	12.1
1A-9L	800	L	92.3	117.4	12	11.7
1A-14L	800	L	93.3	119.7	11	12.4
1A-19L	800	L	93.3	122.2	13	12.6
1A-24L	800	L	92.8	121.3	13	12.5
1A-29L	800	L	93.9	120.1	13	11.[illegible]
1A-34L	800	L	93.3	119.9	13	11.[illegible]
1A-39L	800	L	91.9	121.8	13	13.1
1A-44L	800	L	91.5	119.3	13	12.6
1A-49L	800	L	93.8	121.1	12	11.7
1A-4T	800	T	95.0	117.6	13	14.0
1A-9T	800	T	96.4	117.4	12	12.9
1A-14T	800	T	95.0	116.8	12	12.3
1A-19T	800	T	95.5	118.6	11	14.3
1A-24T	800	T	95.9	118.6	13	13.1
1A-29T	800	T	95.8	115.7	12	12.9
1A-34T	800	T	95.8	115.5	12	12.9
1A-39T	800	T	95.2	116.3	12	13.7
1A-44T	800	T	96.4	118.3	11	13.6
1A-49T	800	T	97.3	117.8	11	13.5

Table 38 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
1A-5L	1000	L	81.7	106.7	14	11.6
1A-10L	1000	L	81.8	107.7	12	12.7
1A-15L	1000	L	83.5	107.8	14	11.7
1A-20L	1000	L	81.8	109.2	12	13.1
1A-25L	1000	L	83.3	108.9	11	11.6
1A-30L	1000	L	84.9	109.1	12	11.3
1A-35L	1000	L	81.9	107.5	13	12.5
1A-40L	1000	L	83.2	108.2	12	11.7
1A-45L	1000	L	85.2	106.7	12	12.1
1A-50L	1000	L	85.5	110.1	13	12.1
1A-5T	1000	T	85.8	107.6	13	11.7
1A-10T	1000	T	88.7	108.4	10	12.4
1A-15T	1000	T	87.4	107.1	11	12.0
1A-20T	1000	T	88.0	108.0	10	12.3
1A-25T	1000	T	88.8	108.7	10	11.3
1A-30T	1000	T	87.3	106.9	11	13.0
1A-35T	1000	T	88.8	106.4	11	11.0
1A-40T	1000	T	85.5	107.8	11	12.8
1A-45T	1000	T	86.0	106.6	10	12.6
1A-50T	1000	T	86.4	107.6	11	12.9

[a] Thickness: 40 mils.

[b] Heat treatment: 1550°F, 1/2 hr, A.C. + 1400°F, 1/4 hr, A. C.

Table 39

Tensile Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet from Heat No. V-1991 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	ϵ %	E_t 10^6 psi
1B-1L	70	L	135.8	149.2	12	14.7
1B-6L	70	L	136.0	149.5	13	14.9
1B-11L	70	L	139.0	149.5	13	14.6
1B-16L	70	L	136.0	148.0	13	15.0
1B-21L	70	L	137.0	149.0	13	15.7
1B-26L	70	L	140.0	151.0	13	15.3
1B-31L	70	L	140.0	150.0	11	14.8
1B-36L	70	L	139.0	150.0	13	16.5
1B-41L	70	L	137.0	149.5	12	15.9
1B-46L	70	L	141.0	149.0	13	15.4
1B-1T	70	T	138.0	147.0	12	15.3
1B-6T	70	T	139.0	147.8	12	17.0
1B-11T	70	T	138.5	147.0	11	16.6
1B-16T	70	T	138.0	146.0	11	16.2
1B-21T	70	T	138.0	147.0	13	16.2
1B-26T	70	T	138.5	147.0	13	16.0
1B-31T	70	T	140.0	148.5	13	16.5
1B-36T	70	T	133.0	141.5	11	15.9
1B-41T	70	T	139.0	148.0	11	16.0
1B-46T	70	T	139.5	148.0	11	16.0
1B-2L	400	L	105.0	123.0	11	13.8
1B-7L	400	L	107.5	125.0	9	13.6
1B-12L	400	L	106.5	125.0	12	13.5
1B-17L	400	L	107.0	124.5	10	12.3
1B-22L	400	L	108.5	124.2	11	13.6
1B-27L	400	L	108.5	124.2	11	13.0
1B-32L	400	L	106.2	123.5	11	14.4
1B-37L	400	L	106.1	123.9	11	13.6
1B-42L	400	L	105.5	124.9	10	14.1
1B-47L	400	L	104.8	123.7	15	14.6
1B-2T	400	T	107.5	121.7	8	15.0
1B-7T	400	T	108.5	121.8	8	14.9
1B-12T	400	T	109.0	122.6	9	14.4
1B-17B	400	T	111.0	122.5	9	14.6
1B-22T	400	T	108.0	120.0	10	14.2
1B-27T	400	T	110.5	122.3	9	13.6
1B-32T	400	T	107.5	120.3	8	14.3
1B-42T	400	T	109.7	122.0	9	13.7
1B-47T	400	T	110.0	125.7	9	14.6
1B-56T	400	T	109.7	121.6	9	14.6

Table 39 (Continued)

Specimen No.	Temp., °F	Orientation	Fty ksi	Ftu ksi	e %	Et 10^6 psi
1B-3L	600	L	97.2	121.1	11	12.9
1B-8L	600	L	95.3	121.4	13	13.0
1B-13L	600	L	96.8	119.0	12	11.1
1B-18L	600	L	97.2	120.6	11	13.9
1B-23L	600	L	95.5	120.4	11	13.6
1B-28L	600	L	96.8	119.8	11	11.1
1B-33L	600	L	95.8	117.9	10	12.9
1B-38L	600	L	97.8	120.7	11	13.8
1B-43L	600	L	97.0	119.3	11	12.7
1B-48L	600	L	96.5	118.3	10	12.3
1B-3T	600	T	98.3	114.0	9	12.6
1B-8T	600	T	99.3	114.3	10	11.6
1B-13T	600	T	101.9	117.2	9	12.2
1B-18T	600	T	102.2	117.4	9	12.0
1B-23T	600	T	99.8	114.1	9	12.4
1B-28T	600	T	100.0	114.7	10	11.9
1B-33T	600	T	100.9	117.5	9	13.5
1B-38T	600	T	100.8	116.1	11	12.6
1B-43T	600	T	98.8	115.3	10	11.7
1B-48T	600	T	97.3	113.2	11	12.8
1B-9L	800	L	92.7	118.3	12	11.5
1B-14L	800	L	93.4	118.4	13	12.1
1B-19L	800	L	92.8	117.6	12	11.8
1B-24L	800	L	92.0	117.0	13	12.2
1B-29L	800	L	92.6	117.9	12	11.7
1B-34L	800	L	93.6	117.2	11	11.9
1B-39L	800	L	92.8	116.2	12	13.2
1B-44L	800	L	92.8	116.2	12	11.5
1B-49L	800	L	92.4	118.3	13	12.2
1B-58L	800	L	93.2	118.8	12	12.1
1B-4T	800	T	93.7	113.6	15	13.7
1B-9T	800	T	94.8	113.8	11	13.1
1B-14T	800	T	96.4	116.4	13	13.1
1B-19T	800	T	92.4	113.3	11	14.3
1B-24T	800	T	94.7	114.9	13	13.0
1B-29T	800	T	94.2	111.6	13	11.8
1B-34T	800	T	96.7	113.9	12	11.8
1B-39T	800	T	95.8	115.2	13	12.6
1B-44T	800	T	95.6	114.6	13	11.8
1B-49T	800	T	94.0	112.4	14	12.2

Table 39 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
1B-15L	1000	L	79.7	102.3	14	11.2
1B-20I	1000	L	83.2	105.9	12	11.3
1B-25L	1000	L	78.3	103.5	12	12.2
1B-30L	1000	L	85.0	106.6	11	11.2
1B-35L	1000	L	84.1	107.8	12	12.0
1B-40L	1000	L	81.7	102.7	14	11.3
1B-45L	1000	L	84.6	105.1	12	10.4
1B-50L	1000	L	77.8	104.1	13	10.8
1B-52L	1000	L	78.8	104.2	13	12.2
1B-53L	1000	L	83.4	106.8	13	10.1
1B-5T	1000	T	86.9	104.5	12	11.7
1B-10T	1000	T	84.8	101.9	11	11.9
1B-15T	1000	T	83.7	102.4	12	11.3
1B-20T	1000	T	82.8	102.5	12	11.4
1B-25T	1000	T	84.5	101.3	12	10.7
1B-30T	1000	T	85.7	105.4	13	10.8
1B-35T	1000	T	87.6	103.6	10	11.9
1B-40T	1000	T	84.5	101.4	12	11.0
1B-45T	1000	T	83.1	101.1	12	11.7
1B-50T	1000	T	82.2	99.2	12	11.2

[a] Thickness: 40 mils.
[b] Heat treatment: 1550°F, 1/2 hr, A. C. + 1400°F, 1/4 hr, A. C.

Table 40

Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet from Heat No. V-3016 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2A-1L	70	L	143.0	150.3	12	16.1
2A-6L	70	L	143.9	149.6	11	16.6
2A-11L	70	L	146.2	152.2	13	16.2
2A-16L	70	L	144.7	148.4	11	16.7
2A-21L	70	L	143.8	149.2	12	1[illegible].7
2A-26L	70	L	141.8	145.9	13	16.0
2A-31L	70	L	142.6	148.9	11	16.1
2A-36L	70	L	138.5	142.5	15	16.0
2A-41L	70	L	137.3	142.2	11	15.7
2A-46L	70	L	140.6	147.5	13	15.9
2A-1T	70	T	137.8	144.5	12	15.9
2A-6T	70	T	139.5	143.5	13	15.9
2A-11T	70	T	138.0	145.6	12	15.5
2A-16T	70	T	138.0	144.6	13	16.1
2A-21T	70	T	140.2	146.5	6	16.5
2A-26T	70	T	141.2	144.6	12	16.1
2A-31T	70	T	139.5	145.5	12	16.0
2A-36T	70	T	138.0	141.4	13	15.4
2A-41T	70	T	138.4	142.3	11	15.7
2A-46T	70	T	140.4	145.4	12	15.8
2A-2[illegible]	400	L	109.8	124.6	11	15.1
2A-7L	400	L	108.2	122.8	11	15.3
2A-12L	400	L	110.2	124.6	11	14.7
2A-17L	400	L	109.8	125.3	11	14.6
2A-22L	400	L	107.7	122.8	10	15.4
2A-27L	400	L	103.9	116.6	11	14.0
2A-32L	400	L	105.2	121.1	10	14.4
2A-37L	400	L	104.5	117.0	13	13.1
2A-42L	400	L	104.5	117.5	12	15.1
2A-47L	400	L	104.9	120.0	11	12.6
2A-2T	400	T	103.9	119.5	12	16.0
2A-7T	400	T	102.9	115.0	12	16.2
2A-12T	400	T	106.8	121.8	11	14.9
2A-17T	400	T	106.0	120.5	11	16.1
2A-22T	400	T	107.0	120.0	8	14.5
2A-27T	400	T	103.4	116.6	12	15.0
2A-32T	400	T	104.0	118.5	11	15.2
2A-37T	400	T	102.1	113.8	13	12.6
2A-42T	400	T	104.5	116.0	12	14.1
2A-47T	400	T	104.0	119.5	12	13.3

Table 40 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2A-3L	600	L	98.0	116.5	7	13.4
2A-8L	600	L	96.8	116.0	8	15.9
2A-13L	600	L	97.3	117.0	9	13.8
2A-18L	600	L	97.5	117.3	7	12.4
2A-23L	600	L	96.6	116.0	8	13.5
2A-28L	600	L	93.5	111.7	10	13.0
2A-33L	600	L	96.6	116.5	10	13.0
2A-38L	600	L	95.2	114.2	10	12.1
2A-43L	600	L	92.8	111.3	11	13.2
2A-48L	600	L	94.4	113.4	11	12.4
2A-3T	600	T	94.6	113.0	10	14.5
2A-8T	600	T	93.5	110.0	10	14.7
2A-13T	600	T	96.3	115.5	9	12.4
2A-18T	600	T	94.3	114.0	10	13.1
2A-23T	600	T	92.4	111.8	10	13.5
2A-28T	600	T	92.9	112.4	10	13.9
2A-33T	600	T	94.0	114.0	10	13.7
2A-38T	600	T	90.2	108.2	10	12.0
2A-43T	600	T	92.3	111.5	12	13.8
2A-48T	600	T	91.0	109.5	11	14.9
2A-4L	800	L	94.6	114.9	10	13.0
2A-9L	800	L	95.5	118.0	10	15.7
2A-14L	800	L	94.4	116.1	10	13.1
2A-19L	800	L	94.4	116.6	9	14.4
2A-24L	800	L	93.0	116.6	12	13.5
2A-29L	800	L	87.7	110.0	12	13.8
2A-34L	800	L	86.8	106.5	15	11.6
2A-39L	800	L	90.7	114.8	11	15.1
2A-44L	800	L	89.6	112.4	13	13.3
2A-49L	800	L	90.0	112.0	10	13.6
2A-4T	800	T	88.7	109.8	11	10.9
2A-9T	800	T	89.7	110.8	10	12.5
2A-14T	800	T	91.6	114.5	12	12.9
2A-19T	800	T	90.3	113.2	11	12.6
2A-24T	800	T	89.8	112.1	10	11.7
2A-29T	800	T	88.3	110.8	11	11.6
2A-34T	800	T	88.5	110.9	13	12.7
2A-39T	800	T	86.8	109.8	14	12.3
2A-44T	800	T	87.0	109.8	13	12.9
2A-49T	800	T	86.7	111.4	13	13.3

Table 40 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2A-10L	1000	L	90.4	112.7	11	12.3
2A-15L	1000	L	85.8	108.0	14	11.0
2A-20L	1000	L	87.8	110.5	11	10.9
2A-25L	1000	L	86.8	110.0	11	11.7
2A-30L	1000	L	85.7	107.2	12	9.9
2A-35L	1000	L	82.0	101.0	16	10.7
2A-40L	1000	L	85.2	107.8	12	12.5
2A-45L	1000	L	82.3	104.0	16	11.2
2A-50L	1000	L	81.3	102.5	14	12.6
2A-168L	1000	L	83.0	104.0	14	11.8
2A-5T	1000	T	83.2	104.0	13	11.0
2A-10T	1000	T	85.6	107.8	14	12.5
2A-15T	1000	T	87.3	108.8	14	12.0
2A-20T	1000	T	85.6	107.8	12	11.8
2A-25T	1000	T	84.6	105.5	14	10.2
2A-30T	1000	T	83.3	104.3	14	11.4
2A-35T	1000	T	80.0	102.4	14	12.9
2A-40T	1000	T	82.5	102.8	15	10.9
2A-45T	1000	T	81.9	102.8	15	11.6
2A-50T	1000	T	82.8	104.4	14	11.1

[a] Thickness: 40 mils
[b] Heat treatment: 1650°F, 1/2 hr, A. C., 1450°F, 1/4 hr, A. C.

Table 41

Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet from Heat No. V-3076 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2B-1L	70	L	143.8	152.9	11	17.0
2B-6L	70	L	140.0	148.5	11	16.5
2B-11L	70	L	139.5	147.5	10	16.2
2B-16L	70	L	138.6	149.0	11	15.8
2B-21L	70	L	142.0	146.2	11	16.5
2B-26L	70	L	144.0	155.0	11	17.1
2B-31L	70	L	142.5	153.8	10	16.7
2B-36L	70	L	141.9	152.8	12	16.5
2B-41L	70	L	143.9	153.2	10	17.0
2B-46L	70	L	142.6	152.2	11	16.9
2B-1T	70	T	134.4	145.9	11	15.4
2B-6T	70	T	134.0	145.4	11	15.1
2B-11T	70	T	134.8	145.2	12	16.0
2B-16T	70	T	135.3	147.5	13	15.5
2B-21T	70	T	135.7	146.5	11	15.7
2B-26T	70	T	136.3	147.1	11	15.7
2B-31T	70	T	133.5	144.5	11	15.2
2B-36T	70	T	133.2	145.0	11	16.0
2B-41T	70	T	135.4	147.2	11	16.3
2B-46T	70	T	134.2	145.5	12	15.1
2B-2L	400	L	108.5	124.4	10	14.9
2B-7L	400	L	108.5	124.4	11	14.0
2B-12L	400	L	107.2	123.4	10	14.6
2B-17L	400	L	108.5	126.0	11	15.7
2B-22L	400	L	111.8	125.4	9	14.2
2B-27L	400	L	109.9	128.4	9	15.6
2B-32L	400	L	110.8	129.2	9	14.7
2B-37L	400	L	109.5	127.6	10	15.2
2B-42L	400	L	112.9	126.3	10	15.1
2B-47L	400	L	109.1	126.5	9	13.9
2B-2T	400	T	102.6	120.8	10	13.7
2B-7T	400	T	103.2	121.2	10	14.3
2B-12T	400	T	103.7	121.9	12	13.9
2B-17T	400	T	102.1	119.7	10	14.0
2B-22T	400	T	102.7	120.3	12	18.5
2B-27T	400	T	102.4	120.0	11	12.8
2B-32T	400	T	102.9	120.7	10	13.4
2B-37T	400	T	102.0	120.7	11	12.8
2B-42T	400	T	103.4	121.7	11	15.3
2B-47T	400	T	103.2	121.9	12	15.6

Table 41 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2B-3L	600	L	97.7	117.5	7	13.6
2B-8L	600	L	95.6	115.2	9	14.4
2B-13L	600	L	95.3	116.4	8	14.8
2B-18L	600	L	98.8	119.6	8	13.2
2B-23L	600	L	102.2	122.1	8	15.6
2B-28L	600	L	100.0	121.0	7	14.9
2B-33L	600	L	100.5	122.0	7	15.8
2B-38L	600	L	99.3	119.6	7	15.3
2B-43L	600	L	99.3	119.6	7	14.9
2B-48L	600	L	100.0	119.8	8	14.7
2B-3T	600	T	92.3	114.6	9	11.5
2B-8T	600	T	91.8	115.2	9	14.4
2B-13T	600	T	92.6	115.7	9	13.3
2B-18T	600	T	91.6	115.0	9	12.5
2B-23T	600	T	92.4	115.8	10	14.1
2B-28T	600	T	93.6	116.4	9	13.8
2B-33T	600	T	92.0	114.8	9	12.9
2B-38T	600	T	92.2	115.7	9	12.9
2B-43T	600	T	93.2	116.4	9	13.6
2B-48T	600	T	92.0	115.0	9	13.2
2B-4L	800	L	93.7	116.5	9	13.9
2B-9L	800	L	89.7	112.2	10	12.8
2B-14L	800	L	92.4	113.4	9	13.2
2B-19L	800	L	93.0	114.5	9	12.0
2B-24L	800	L	96.4	119.0	9	13.6
2B-29L	800	L	95.7	117.9	7	14.5
2B-34L	800	L	94.4	118.5	9	14.6
2B-39L	800	L	93.7	119.6	8	16.5
2B-44L	800	L	95.6	117.8	8	13.2
2B-49L	800	L	94.6	116.9	10	12.6
2B-4T	800	T	86.8	113.7	12	11.4
2B-9T	800	T	87.3	113.2	10	12.9
2B-14T	800	T	88.2	114.4	10	12.1
2B-19T	800	T	87.0	113.2	11	12.6
2B-24T	800	T	88.3	115.8	13	13.6
2B-29T	800	T	89.2	114.2	10	13.0
2B-34T	800	T	87.3	112.4	11	11.1
2B-39T	800	T	86.8	113.8	10	13.2
2B-44T	800	T	88.3	113.2	11	11.8
2B-49T	800	T	88.3	114.2	10	13.0

Table 41 (Continued)

Specimen No.	Temp., °F	Orientation	F_{ty} ksi	F_{tu} ksi	e %	E_t 10^6 psi
2B-5L	1000	L	79.0	105.2	17	14.4
2B-10L	1000	L	80.8	103.0	13	12.8
2B-15L	1000	L	82.3	103.6	14	11.4
2B-20L	1000	L	83.8	109.7	11	13.6
2B-25L	1000	L	85.0	111.8	12	14.3
2B-30L	1000	L	90.3	112.5	10	12.6
2B-35L	1000	L	82.8	108.2	13	13.5
2B-40L	1000	L	85.0	109.0	13	12.5
2B-45L	1000	L	84.2	107.8	12	13.0
2B-50L	1000	L	84.6	108.9	12	13.8
2B-5T	1000	T	79.7	102.2	14	11.5
2B-10T	1000	T	80.2	103.1	14	11.3
2B-15T	1000	T	78.4	102.6	15	11.2
2B-20T	1000	T	79.7	103.7	15	10.7
2B-25T	1000	T	81.8	104.4	14	11.7
2B-30T	1000	T	80.2	102.2	15	10.9
2B-35T	1000	T	77.7	102.2	14	10.7
2B-40T	1000	T	80.7	104.2	15	10.8
2B-45T	1000	T	81.0	104.2	13	10.9
2B-50T	1000	T	78.5	103.2	9	11.1

[a] Thickness: 40 mils
[b] Heat treatment: 1650°F, 1/2 hr, A.C., 1450°F, 1/4 hr, A.C.

Table 42

Notched Tensile Properties of the Sheet Alloys[a, b, c, d]

Alloy	Specimen No.	Temp., °F	Notched Tensile Strength, ksi
Ti-5Al-5Sn-5Zr	5B-52L	70	166.7
	5B-53L	70	166.8
	5B-51L	400	120.2
	5B-54L	400	122.0
	5B-56L	800	104.9
	5B-57L	800	105.8
Ti-5Al-5Sn-5Zr-1Mo-1V	1A-173L	70	165.0
	1A-174L	70	165.8
	1A-163L	400	132.0
	1A-165L	400	131.0
	1A-161L	800	133.2
	1A-168L	800	130.9
	1A-171L	800	128.6
Ti-6Al-2Sn-4Zr-2Mo	2B-51L	70	171.5
	2B-52L	70	168.7
	2B-53L	400	137.4
	2B-54L	400	138.0
	2B-55L	800	133.8
	2B-56L	800	131.2

a Thickness: 40 mils

b Heat treatment:
Ti-5Al-5Sn-5Zr, 1650° F, 1/2 hr, A.C.
Ti-5Al-5Sn-5Zr-1Mo-1V, 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
Ti-6Al-2Sn-4Zr-2Mo, 1650° F, 1/4 hr, A.C. + 1450° F, 1/4 hr, A.C.

c Notched 45°, 0.025 in. radius, 0.375 in. minimum width to produce $K_t = 3$

d All tests in longitudinal direction

Table 43

Compression Properties of Ti-5Al-5Sn-5Zr Alloy Sheet at Different Temperatures[a, b, c]

Temp., °F	Longitudinal Orientation Specimen Number	F_{cy}, ksi	E_c 10^6 psi	Transverse Orientation Specimen Number	F_{cy}, ksi	E_c 10^6 psi
70	5A-370	120.6	14.9	5A-117	123.7	14.9
70	5A-351	116.5	14.3	5A-122	124.4	15.0
70	5A-356	117.8	14.2	5A-127	126.8	15.3
70	5A-361	121.0	14.5	5A-132	127.2	15.1
70	5A-366	119.0	14.1	5A-137	126.8	15.2
400	5A-347	79.7	12.3	5A-118	82.7	13.0
400	5A-353	80.9	11.6	5A-123	82.7	12.8
400	5A-357	80.3	12.0	5A-128	82.7	12.8
400	5A-362	79.8	12.1	5A-133	81.6	12.8
400	5A-367	80.2	12.2	5A-138	82.0	12.8
600	5A-348	67.5	11.3	5A-119	67.3	12.5
600	5A-353	64.6	11.1	5A-124	68.7	11.6
600	5A-358	66.8	11.9	5A-129	68.2	12.0
600	5A-333	67.7	10.1	5A-134	69.4	12.2
600	5A-368	66.8	10.1	5A-139	68.6	12.3
800	5A-349	59.3	10.2	5A-120	63.1	11.9
800	5A-354	60.0	10.6	5A-125	62.2	11.1
800	5A-359	59.3	10.7	5A-130	62.5	11.8
800	5A-364	60.7	10.4	5A-135	63.1	11.7
800	5A-369	62.2	11.0	5A-140	63.1	11.4
1000	5A-350	58.2	9.9	5A-121	60.9	10.1
1000	5A-355	57.8	9.5	5A-126	58.6	10.3
1000	5A-360	57.6	9.6	5A-131	60.4	10.4
1000	5A-365	57.2	9.6	5A-136	59.7	10.3
1000	5A-346	59.3	10.0	5A-141	59.5	10.5

a Heat No. D-8060.

b Thickness: 40 mils.

c Heat treatment: 1650° F, 1/4 hr, A.C.

Table 44

Compression Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet at Different Temperatures[a, b, c]

Temp., °F	Longitudinal Orientation Specimen Number	Longitudinal Orientation F_{cy}, ksi	Longitudinal Orientation E_c 10^6 psi	Transverse Orientation Specimen Number	Transverse Orientation F_{cy}, ksi	Transverse Orientation E_c 10^6 psi
70	1A-371	144.0	14.6	1A-117	150.5	14.9
70	1A-351	141.0	14.1	1A-122	156.3	15.4
70	1A-356	138.5	14.8	1A-127	153.7	15.4
70	1A-361	144.1	14.5	1A-132	153.7	15.4
70	1A-366	142.0	14.3	1A-137	156.2	15.2
400	1A-347	94.3	12.7	1A-118	112.2	13.7
400	1A-352	106.5	12.8	1A-123	113.5	13.7
400	1A-357	103.4	12.5	1A-128	113.0	13.4
400	1A-362	108.0	12.8	1A-133	114.5	13.7
400	1A-367	106.5	12.6	1A-138	115.1	12.4
600	1A-348	101.0	12.0	1A-119	103.0	12.4
600	1A-353	93.2	11.4	1A-124	103.5	12.4
600	1A-358	98.3	11.3	1A-129	102.5	11.8
600	1A-363	98.7	11.3	1A-134	105.1	12.6
600	1A-368	97.8	11.8	1A-139	102.3	12.0
800	1A-349	93.3	11.2	1A-120	98.5	12.2
800	1A-354	90.4	11.1	1A-125	97.3	11.4
800	1A-359	93.5	11.2	1A-130	102.6	12.1
800	1A-364	93.6	11.0	1A-135	99.7	11.9
800	1A-369	95.5	11.2	1A-140	97.9	11.8
1000	1A-350	81.4	10.4	1A-121	88.9	10.7
1000	1A-355	84.4	10.1	1A-126	86.7	10.5
1000	1A-360	83.5	10.4	1A-131	89.8	10.5
1000	1A-365	86.3	9.6	1A-136	90.4	10.8
1000	1A-370	83.3	9.9	1A-141	88.5	10.3

a Heat No. V-2957.
b Thickness: 40 mils.
c Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

Table 45

Compression Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet at Different Temperatures[a,b,c]

Temp., °F	Longitudinal Orientation Specimen Number	F_{cy}, ksi	E_c 10^6 psi	Transverse Orientation Specimen Number	F_{cy}, ksi	E_c 10^6 psi
70	2A-345	144.7	13.1	2A-117	142.7	14.6
70	2A-351	151.6	14.3	2A-122	148.9	14.7
70	2A-356	154.3	14.8	2A-127	148.5	14.6
70	2A-361	144.5	14.4	2A-132	137.4	14.0
70	2A-366	152.8	14.6	2A-137	144.6	14.6
400	2A-347	116.8	12.9	2A-118	107.1	12.0
400	2A-352	114.0	12.9	2A-123	107.5	12.6
400	2A-357	107.4	12.8	2A-128	107.5	12.7
400	2A-362	111.4	12.7	2A-133	102.0	12.5
400	2A-370	107.1	12.3	2A-138	105.6	12.9
600	2A-348	96.1	12.2	2A-119	93.3	11.2
600	2A-353	106.4	12.2	2A-124	94.6	11.3
600	2A-358	99.3	11.9	2A-129	100.3	11.8
600	2A-363	97.8	11.8	2A-134	90.3	11.6
600	2A-368	98.9	12.2	2A-139	98.8	11.6
800	2A-349	104.5	11.8	2A-120	90.0	10.7
800	2A-354	94.8	11.9	2A-125	90.0	11.6
800	2A-359	97.6	11.1	2A-130	83.8	10.9
800	2A-364	88.0	10.3	2A-135	86.9	11.1
800	2A-369	97.6	11.4	2A-140	89.1	10.8
1000	2A-350	88.4	10.8	2A-121	84.5	10.3
1000	2A-355	89.9	11.4	2A-126	84.5	10.4
1000	2A-360	84.0	10.5	2A-131	77.4	10.0
1000	2A-365	78.5	10.1	2A-136	84.5	10.2
1000	2A-346	85.8	10.3	2A-141	80.7	10.0

a Heat No. V-3016.
b Thickness: 40 mils.
c Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

Table 46

Bearing Properties of Ti-5Al-5Sn-5Zr Alloy Sheet
At Different Temperatures[a, b, c]

Temp. °F	Orientation	e/D = 1.5 Specimen No.	e/D = 1.5 F_{by} ksi	e/D = 1.5 F_{bu} ksi	e/D = 2.0 Specimen No.	e/D = 2.0 F_{by} ksi	e/D = 2.0 F_{bu} ksi
70	L	5A-314L	176.8	200.0	5A-313L	200.5	239.5
70	L	5A-322L	180.3	205.2	5A-325L	211.0	259.3
70	L	5A-332L	183.7	201.5	5A-335L	204.5	255.5
70	T	5A-86T	186.1	215.5	5A-85T	220.5	280.8
70	T	5A-96T	184.7	219.0	5A-95T	215.5	273.8
70	T	5A-106T	182.0	220.5	5A-105T	211.6	261.5
400	L	5A-316L	132.3	158.1	5A-315L	153.6	190.5
400	L	5A-324L	131.0	154.7	5A-327L	159.0	200.0
400	L	5A-334L	134.3	156.8	5A-336L	156.1	200.0
400	T	5A-88T	132.8	165.7	5A-87T	154.5	214.3
400	T	5A-98T	136.4	168.7	5A-97T	168.1	218.3
400	T	5A-108T	136.3	167.8	5A-107T	165.8	219.6
600	L	5A-318L	115.2	140.4	5A-317L	140.3	179.0
600	L	5A-326L	116.1	141.3	5A-329L	143.9	177.5
600	L	5A-339L	116.4	140.9	5A-337L	143.8	185.5
600	T	5A-90T	117.3	154.0	5A-89T	140.4	199.0
600	T	5A-100T	116.7	150.4	5A-99T	143.2	199.3
600	T	5A-110T	121.4	151.7	5A-109T	143.5	195.8
800	L	5A-320L	104.1	130.5	5A-319L	125.2	174.2
800	L	5A-328L	112.0	134.3	5A-331L	126.8	167.1
800	L	5A-340L	105.5	135.8	5A-338L	131.2	172.5

Table 46 (Continued)

Temp. °F	Orientation	Specimen No.	F_{by} ksi	F_{bu} ksi	Specimen No.	F_{by} ksi	F_{bu} ksi
800	T	5A-92T	109.1	146.0	5A-91T	132.2	189.2
800	T	5A-102T	108.3	143.5	5A-101T	138.0	191.2
800	T	5A-112T	109.2	140.2	5A-111T	132.2	185.5
1000	L	5A-321L	99.4	123.1	5A-323L	116.0	163.1
1000	L	5A-330L	103.6	126.3	5A-333L	118.3	163.6
1000	L	5A-342L	104.3	126.4	5A-341L	123.4	165.0
1000	T	5A-94T	105.4	136.5	5A-93T	122.6	177.3
1000	T	5A-104T	106.3	140.0	5A-103T	130.2	175.5
1000	T	5A-114T	106.3	134.7	5A-113T	128.6	177.3

[a] Heat No. D-8060

[b] Thickness: 40 mils

[c] Heat Treatment: 1650°F, ½ hr, A. C.

Table 47

Bearing Properties of Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet At Different Temperatures[a, b, c]

Temp. °F	Orientation	e/D = 1.5 Specimen No.	F_{by} ksi	F_{bu} ksi	e/D = 2.0 Specimen No.	F_{by} ksi	F_{bu} ksi
70	L	1A-323L	202.5	221.0	1A-314L	224.9	267.5
70	L	1A-343L	201.5	221.0	1A-324L	266.5	300.0
70	L	1A-313L	204.5	219.0	1A-334L	238.0	274.0
70	T	1A-95T	211.0	231.5	1A-106T	276.5	283.8
70	T	1A-85T	211.0	238.0	1A-115T	275.0	294.4
70	T	1A-105T	207.0	236.0	1A-116T	261.0	283.5
400	L	1A-316L	164.1	188.5	1A-315L	198.9	228.0
400	L	1A-326L	168.1	187.6	1A-325L	202.5	240.5
400	L	1A-336L	165.0	180.3	1A-335L	197.2	236.2
400	T	1A-88T	167.0	199.8	1A-87T	205.0	240.0
400	T	1A-98T	172.9	204.3	1A-97T	207.0	224.0
400	T	1A-108T	173.5	202.5	1A-107T	211.6	236.2
600	L	1A-318L	159.5	177.8	1A-317L	186.1	221.0
600	L	1A-328L	161.9	176.5	1A-327L	197.3	224.0
600	L	1A-338L	159.5	180.8	1A-337L	186.7	220.5
600	T	1A-90T	164.8	194.0	1A-89T	199.8	216.0
600	T	1A-100T	161.8	195.2	1A-99T	192.6	220.0
600	T	1A-110T	166.8	196.6	1A-109T	191.3	205.0
800	L	1A-320L	161.7	174.2	1A-319L	197.4	217.8
800	L	1A-330L	156.4	171.3	1A-329L	179.5	206.3
800	L	1A-340L	154.5	168.1	1A-339L	175.3	202.8

Table 47 (Continued)

Temp. °F	Orientation	e/D = 1.5 Specimen No.	F_{by} ksi	F_{bu} ksi	e/D = 2.0 Specimen No.	F_{by} ksi	F_{bu} ksi
800	T	1A-92T	157.7	194.8	1A-91T	196.0	202.5
800	T	1A-102T	157.7	187.2	1A-101T	189.6	195.5
800	T	1A-112T	155.3	176.8	1A-111T	197.7	210.0
1000	L	1A-322L	155.1	176.3	1A-321L	179.5	205.0
1000	L	1A-332L	147.8	172.6	1A-331L	162.0	196.7
1000	L	1A-342L	149.2	170.0	1A-341L	172.6	202.5
1000	T	1A-94T	155.2	177.5	1A-93T	190.4	202.5
1000	T	1A-104T	150.5	180.5	1A-103T	181.7	205.1
1000	T	1A-114T	153.5	181.6	1A-113T	178.3	196.7

[a]Heat No. V-2957

[b]Thickness: 40 mils

[c]Heat Treatment: 1550°F, $\frac{1}{2}$ hr, A. C. + 1400°F, $\frac{1}{4}$ hr, A. C.

Table 48

Bearing Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet At Different Temperatures[a, b, c]

Temp. °F	Orientation	e/D = 1.5 Specimen No.	e/D = 1.5 F_{by} ksi	e/D = 1.5 F_{bu} ksi	e/D = 2.0 Specimen No.	e/D = 2.0 F_{by} ksi	e/D = 2.0 F_{bu} ksi
70	L	2A-314L	203.0	238.0	2A-313L	236.7	296.0
70	L	2A-324L	198.3	233.6	2A-323L	240.0	290.1
70	L	2A-332L	201.2	230.8	2A-335L	234.0	291.0
70	T	2A-86T	201.2	236.3	2A-85T	235.0	277.0
70	T	2A-96T	199.8	234.0	2A-97T	245.5	298.5
70	T	2A-106T	194.8	226.0	2A-107T	232.1	287.8
400	L	2A-316L	157.5	188.0	2A-315L	198.4	250.3
400	L	2A-325L	159.0	190.2	2A-326L	194.8	239.5
400	L	2A-334L	157.2	185.3	2A-337L	187.5	240.2
400	T	2A-88T	159.6	190.8	2A-89T	184.3	232.0
400	T	2A-98T	164.3	192.9	2A-99T	195.1	246.2
400	T	2A-108T	157.1	186.0	2A-109T	189.2	244.0
600	L	2A-318L	149.8	185.3	2A-317L	181.7	223.8
600	L	2A-327L	148.7	181.0	2A-329L	171.2	228.0
600	L	2A-336L	141.8	171.7	2A-340L	177.7	224.5
600	T	2A-90T	144.5	177.5	2A-91T	174.8	231.6
600	T	2A-100T	143.1	172.5	2A-101T	165.5	222.5
600	T	2A-110T	139.3	167.9	2A-111T	176.6	222.5
800	L	2A-320L	151.7	181.6	2A-319L	179.2	219.5
800	L	2A-328L	139.6	173.2	2A-331L	174.5	212.0
800	L	2A-338L	136.5	167.8	2A-341L	178.3	220.0

Table 48 (Continued)

Temp. °F	Orientation	e/D = 1.5 Specimen No.	F_{by} ksi	F_{bu} ksi	e/D = 2.0 Specimen No.	F_{by} ksi	F_{bu} ksi
800	T	2A-92T	148.7	177.4	2A-93T	172.4	202.0
800	T	2A-102T	142.5	171.4	2A-103T	172.5	208.2
800	T	2A-112T	145.4	175.0	2A-113T	170.4	203.0
1000	L	2A-322L	149.3	165.0	2A-321L	167.2	208.5
1000	L	2A-330L	136.4	165.0	2A-333L	167.0	214.3
1000	L	2A-342L	138.8	165.2	2A-343L	173.3	211.5
1000	T	2A-94T	140.0	170.0	2A-95T	161.0	205.9
1000	T	2A-104T	143.3	162.6	2A-105T	167.2	204.5
1000	T	2A-114T	139.2	161.0	2A-115T	173.2	205.0

[a]Heat No. V-3016

[b]Thickness: 40 mils

[c]Heat Treatment: 1650°F, ½ hr, A. C. + 1450°F, ¼ hr, A. C.

Table 49

Ultimate Shear Strength of Ti-5Al-5Sn-5Zr Alloy Sheet from Heat No. D-8060 at Different Temperatures[a, b]

Temp., °F	Longitudinal Orientation Specimen No.	Longitudinal Orientation F_{su} ksi	Transverse Orientation Specimen No.	Transverse Orientation F_{su} ksi
70	5A-245L	88.7	5A-57T	95.7
70	5A-250L	88.7	5A-62T	95.2
70	5A-255L	87.5	5A-67T	92.7
70	5A-260L	86.8	5A-72T	92.7
70	5A-265L	86.8	5A-77T	94.7
400	5A-246L	67.3	5A-58T	73.8
400	5A-251L	68.0	5A-63T	71.0
400	5A-256L	67.6	5A-68T	70.6
400	5A-261L	67.3	5A-73T	73.3
400	5A-266L	70.2	5A-78T	75.8
600	5A-247L	62.2	5A-59T	68.8
600	5A-252L	61.7	5A-64T	65.9
600	5A-257L	62.2	5A-69T	66.1
600	5A-262L	61.7	5A-74T	66.7
600	5A-267L	64.4	5A-79T	67.5
800	5A-248L	61.8	5A-60T	66.5
800	5A-253L	58.5	5A-65T	64.6
800	5A-258L	57.8	5A-70T	65.8
800	5A-263L	59.3	5A-75T	65.9
800	5A-268L	60.7	5A-80T	68.0
1000	5A-249L	55.0	5A-61T	62.2
1000	5A-254L	55.8	5A-66T	62.5
1000	5A-259L	55.8	5A-71T	62.5
1000	5A-264L	56.4	5A-76T	62.9
1000	5A-269L	57.8	5A-81T	64.3

[a] Thickness: 40 mils
[b] Heat treatment: 1650°F, 1/2 hr, A.C.

Table 50

Ultimate Shear Strength of Ti-5Al-5Sn-5Zr-1V-1Mo Alloy Sheet from Heat No. V-2957 at Different Temperatures[a, b]

Temp., °F	Longitudinal Orientation: Specimen No.	Longitudinal Orientation: F_{su} ksi	Transverse Orientation: Specimen No.	Transverse Orientation: F_{su} ksi
70	1A-245L	106.2	1A-57T	108.2
70	1A-250L	107.0	1A-62T	111.0
70	1A-255L	105.0	1A-67T	111.0
70	1A-260L	104.2	1A-72T	109.0
70	1A-265L	103.3	1A-77T	110.0
400	1A-246L	87.0	1A-58T	91.5
400	1A-251L	88.5	1A-63T	89.2
400	1A-256L	84.0	1A-68T	92.2
400	1A-261L	83.8	1A-73T	89.0
400	1A-266L	84.6	1A-78T	91.1
600	1A-247L	80.3	1A-59T	88.3
600	1A-252L	81.0	1A-64T	87.0
600	1A-257L	84.1	1A-69T	85.8
600	1A-262L	83.5	1A-74T	85.3
600	1A-267L	83.2	1A-79T	87.0
800	1A-248L	81.0	1A-60T	86.2
800	1A-253L	82.5	1A-65T	84.6
800	1A-258L	82.5	1A-70T	82.6
800	1A-263L	81.1	1A-75T	85.6
800	1A-268L	80.3	1A-80T	86.8
1000	1A-249L	75.1	1A-61T	76.8
1000	1A-254L	74.3	1A-66T	76.8
1000	1A-259L	72.8	1A-71T	77.4
1000	1A-264L	71.6	1A-76T	78.0
1000	1A-269L	70.8	1A-81T	78.8

[a] Thickness: 40 mils
[b] Heat treatment: 1550°F, 1/2 hr, A.C. + 1400°F, 1/4 hr, A.C.

Table 51

Ultimate Shear Strength of Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet from Heat No. V-3016 at Different Temperatures[a, b]

Temp., °F	Longitudinal Orientation Specimen No.	Longitudinal Orientation F_{su} ksi	Transverse Orientation Specimen No.	Transverse Orientation F_{su} ksi
70	2A-245L	99.5	2A-57T	95.7
70	2A-250L	101.3	2A-62T	98.5
70	2A-255L	98.8	2A-67T	95.8
70	2A-260L	93.8	2A-72T	93.8
70	2A-265L	95.8	2A-77T	93.7
400	2A-246L	82.5	2A-58T	78.1
400	2A-251L	82.5	2A-63T	80.8
400	2A-256L	84.3	2A-68T	78.5
400	2A-261L	79.4	2A-73T	78.1
400	2A-266L	80.5	2A-78T	77.3
600	2A-247L	80.7	2A-59T	75.5
600	2A-252L	81.2	2A-64T	76.8
600	2A-257L	80.8	2A-69T	77.4
600	2A-262L	76.1	2A-74T	75.5
600	2A-267L	76.8	2A-79T	72.3
800	2A-248L	80.0	2A-60T	74.2
800	2A-253L	78.7	2A-65T	74.8
800	2A-258L	74.0	2A-70T	70.7
800	2A-263L	74.0	2A-75T	72.8
800	2A-268L	76.0	2A-80T	70.5
1000	2A-249L	70.0	2A-61T	66.5
1000	2A-254L	71.7	2A-66T	69.7
1000	2A-259L	66.5	2A-71T	67.6
1000	2A-264L	68.4	2A-76T	65.9
1000	2A-269L	67.8	2A-81T	66.5

[a] Sheet thickness: 40 mils
[b] Heat treatment: 1650°F, 1/2 hr, A. C. + 1450°F, 1/4 hr, A. C.

Table 52

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		F_{ty}, ksi						
		Test Temperature, °F						
Temp. °F	Time Hr	70	600	800	1000	1100	1150	1200
70	-	118.6						
600	0.25	-	66.3					
600	1000	114.2	63.8					
800	0.25	-	-	61.1				
800	100	118.0	-	63.2				
800	1000	121.1	-	66.9				
1000	0.25	-	-	-	59.0			
1000	10	120.4	-	-	61.0			
1000	100	120.2	-	-	62.8			
1000	1000	120.3	-	-	63.8			
1100	10	118.9	-	-	-	62.8		
1150	10	116.5	-	-	-	-	55.2	
1200	10	119.1	-	-	-	-	-	53.3

Exposure Conditions		F_{tu}, ksi						
		Test Temperature, °F						
Temp. °F	Time Hr	70	600	800	1000	1100	1150	1200
70	-	128.5						
600	0.25	-	89.6					
600	1000	122.2	85.4					
800	0.25	-	-	83.5				
800	100	123.7	-	84.1				
800	1000	126.0	-	86.9				
1000	0.25	-	-	-	79.4			
1000	10	126.6	-	-	80.2			
1000	100	125.8	-	-	81.7			
1000	1000	128.2	-	-	83.0			
1100	10	126.3	-	-	-	82.7		
1150	10	124.9	-	-	-	-	76.3	
1200	10	127.0	-	-	-	-	-	70.2

Table 52 (Continued)

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		e, %						
		Test Temperature, °F						
Temp. °F	Time Hr	70	600	800	1000	1100	1150	1200
70	-	14						
600	0.25	-	18					
600	1000	18	20					
800	0.25	-	-	23				
800	100	18	-	25				
800	1000	18	-	24				
1000	0.25	-	-	-	21			
1000	10	16	-	-	24			
1000	100	16	-	-	22			
1000	1000	15	-	-	18			
1100	10	-	-	-	-	21		
1150	10	15	-	-	-	-	26	
1200	10	14	-	-	-	-	-	33

a. Heat treatment: 1650° F, 1/2 hr, A. C.

b. Results are averages of duplicate tests except those for single specimens exposed and tested at 1100, 1150, and 1200° F.

Table 53

Ultimate Shear Strength of the Ti-5Al-5Sn-5Zr Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature After Different Thermal Exposures[a, b]

Exposure Conditions Temp., °F	Time, Hr	Test Temperature, °F 70	600	800	1000
70	-	87.7			
600	0.25	-	62.4		
600	1000	86.4	62.9		
800	0.75	-	-	59.6	
800	100	85.8	-	59.5	
800	1000	86.2	-	62.1	
1000	0.25	-	-	-	56.2
1000	10	85.4	-	-	56.5
1000	100	85.0	-	-	57.2
1000	1000	84.6	-	-	57.9

a. Heat treatment: 1650° F, 1/2 hr, A. C.
b. All results shown are averages of two tests.

Table 54

Tensile Properties of the Ti-5Al-5Sn-5Zr-1V-1Mo Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		F_{ty}, ksi						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	136.8						
600	0.25	-	97.6					
600	1000	145.5	103.4					
800	0.25	-	-	92.8				
800	100	150.5	-	98.0				
800	1000	155.1	-	102.1				
1000	0.25	-	-	-	83.3			
1000	10	150.2	-	-	88.4			
1000	100	150.6	-	-	81.8			
1000	1000	153.7	-	-	83.3			
1100	10	146.2	-	-	-	68.3		
1150	10	146.6	-	-	-	-	59.2	
1200	10	144.7	-	-	-	-	-	58.1

Exposure Conditions		F_{tu}, ksi						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	146.8						
600	0.25	-	120.2					
600	1000	159.5	127.7					
800	0.25	-	-	120.2				
800	100	163.0	-	124.3				
800	1000	164.5	-	125.6				
1000	0.25	-	-	-	108.2			
1000	10	161.0	-	-	108.5			
1000	100	160.3	-	-	99.1			
1000	1000	160.7	-	-	100.5			
1100	10	155.2	-	-	-	86.6		
1150	10	156.2	-	-	-	-	81.8	
1200	10	153.5	-	-	-	-	-	73.8

Table 54 (Continued)

Tensile Properties of the Ti-5Al-5Sn-5Zr-1V-1Mo Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		e, %						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	11						
600	0.25	-	10					
600	1000	10	8					
800	0.25	-	-	12				
800	100	12	-	8				
800	1000	12	-	10				
1000	0.25	-	-	-	12			
1000	10	12	-	-	12			
1000	100	11	-	-	14			
1000	1000	4	-	-	14			
1100	10	12	-	-	-	16		
1150	10	12	-	-	-	-	24	
1200	10	10	-	-	-	-	-	16

a. Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

b. Results are averages of duplicate tests except those for single specimens exposed and tested at 1100, 1150 and 1200° F.

Table 55

Ultimate Shear Strength of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a,b]

Exposure Conditions Temp. °F	Time, Hr	Test Temperature, °F 70	600	800	1000
70	-	105.1			
600	0.25	-	82.4		
600	1000	109.6	87.6		
800	0.25	-	-	81.5	
800	100	113.6	-	82.4	
800	1000	113.1	-	81.7	
1000	0.25	-	-	-	72.9
1000	10	110.7	-	-	73.7
1000	100	110.4	-	-	71.0
1000	1000	108.6	-	-	71.6

a. Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.

b. All results shown are averages of two tests.

Table 56

Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		F_{ty}, ksi						
Temp. °F	Time Hr	Test Temperature, °F 70	600	800	1000	1100	1150	1200
70	-	142.2						
600	0.25	-	95.9					
600	1000	151.2	100.6					
800	0.25	-	-	91.7				
800	100	152.2	-	96.3				
800	1000	153.7	-	96.7				
1000	0.25	-	-	-	85.0			
1000	10	152.0	-	-	85.3			
1000	100	155.8	-	-	89.9			
1000	1000	156.6	-	-	87.1			
1100	10	151.4	-	-	-	79.5		
1150	10	147.9	-	-	-	-	66.4	
1200	10	143.9	-	-	-	-	-	56.4

Exposure Conditions		F_{tu}, ksi						
Temp. °F	Time Hr	Test Temperature, °F 70	600	800	1000	1100	1150	1200
70	-	147.7						
600	0.25	-	115.0					
600	1000	160.8	122.9					
800	0.25	-	-	113.8				
800	100	163.3	-	126.3				
800	1000	163.4	-	124.2				
1000	0.25	-	-	-	106.8			
1000	10	160.8	-	-	105.8			
1000	100	163.3	-	-	109.3			
1000	1000	160.9	-	-	105.0			
1100	10	155.1	-	-	-	94.5		
1150	10	155.5	-	-	-	-	79.6	
1200	10	150.8	-	-	-	-	-	70.5

Table 56 (Continued)

Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions		e, %						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	12						
600	0.25	-	9					
600	1000	11	10					
800	0.25	-	-	11				
800	100	11	-	9				
800	1000	12	-	10				
1000	0.25	-	-	-	13			
1000	10	12	-	-	14			
1000	100	12	-	-	14			
1000	1000	12	-	-	15			
1100	10	12	-	-	-	19		
1150	10	12	-	-	-	-	27	
1200	10	13	-	-	-	-	-	33

a. Heat treatment: 1650° F, 1/2 hr, A.C., + 1450° F, 1/4 hr, A.C.

b. Results are averages of duplicate tests except those for single specimens exposed and tested at 1100, 1150, and 1200° F.

Table 57

Ultimate Shear Strength of the Ti-6Al-2Sn-4Zr-2Mo Alloy Forty-Mil Sheet at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b]

Exposure Conditions Temp., °F	Time, Hr	Test Temperature, °F 70	600	800	1000
70	-	97.8			
600	0.25	-	79.1		
600	1000	102.4	82.8		
800	0.25	-	-	76.5	
800	100	110.3	-	82.0	
800	1000	108.1	-	81.2	
1000	0.25	-	-	-	68.9
1000	10	107.2	-	-	69.0
1000	100	110.3	-	-	72.8
1000	1000	103.5	-	-	69.3

a. Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

b. All results shown are averages of two tests.

Table 58

Rockwell C Hardness of Sheet Alloys after Exposure at Different Temperatures and Times

		R_c Hardness[a]		
Exposure Temp, ° F	Exposure Time, hr	Ti-5Al-5Sn-5Zr[b,c]	Ti-5Al-5Sn-5Zr-1Mo-1V[b,c]	Ti-6Al-2Sn-4Zr-2Mo[b,c]
RT	-	33.4	34.9	34.3
600	1000	30.7	38.5	35.8
800	100	30.5	38.0	36.4
800	1000	31.8	38.5	35.3
1000	10	34.0	36.8	35.5
1000	100	31.8	35.5	36.2
1000	1000	31.8	37.5	35.6
1100	10	33.3	35.3	34.8
1150	10	31.2	37.5	34.7
1200	10	31.3	33.5	33.0

a Hardness measured on 30-N scale and converted to R_c.
b 40 mil sheet
c Heat treatments:
  Ti-5Al-5Sn-5Zr sheet, 1650° F, 1/2 hr, A.C.
  Ti-5Al-5Sn-5Zr-1Mo-1V sheet, 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
  Ti-6Al-2Sn-4Zr-2Mo sheet, 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.

Table 59

Creep Data for the Ti-5Al-5Sn-5Zr Alloy Sheet[a, b, c]

Specimen Number	Temp., °F	Stress, ksi	Time to creep deformation, hr 0.05%	0.1%	0.2%	0.5%	2.0%	Min. Creep Rate, % hr^{-1}
5A-105L	800	60.0	8	d	d	d	d	$<1.0 \times 10^{-5}$
5A-118L	800	65.0	290	d	d	d	d	8.0×10^{-5}
5A-107L	800	69.0	160	d	d	d	d	4.0×10^{-5}
5A-117L	800	71.0	20	480	d	d	d	7.5×10^{-5}
5A-119L	800	75.0	Deformed excessively on loading					-
5A-113L	900	59.0	50	200	d	d	d	3.0×10^{-4}
5A-166L	900	60.0	110	170	410	d	d	6.0×10^{-4}
5A-160L	900	63.0	5	11	27	72	d	2.8×10^{-3}
5A-168L	900	63.0	19	38	80	220	d	1.8×10^{-3}
5A-97L	900	63.0	2	5	15	51	d	1.9×10^{-3}
5A-122L	900	65.0	1	18	45	120	620	2.4×10^{-3}
5A-120L	900	68.0	1	4	9	39	312	5.4×10^{-3}
5A-99L	900	70.0	-	6	13	30	100	2.3×10^{-2}
5A-115L	900	70.0	2	5	14	42	243	6.6×10^{-2}
5A-106L	900	72.0	-	-	3	9	46	5.1×10^{-2}
5A-176L	1000	28.0	115	350	d	d	d	2.0×10^{-4}
5A-112L	1000	30.0	25	70	370	d	d	3.0×10^{-4}
5A-163L	1000	35.0	19	100	305	d	d	5.5×10^{-4}
5A-114L	1000	35.0	45	70	170	494	d	3.0×10^{-4}
5A-111L	1000	40.0	10	25	55	315	d	7.6×10^{-4}
5A-171L	1000	40.0	5	21	185	215	d	1.3×10^{-3}
5A-109L	1000	45.0	3	17	50	135	285	3.2×10^{-3}
5A-104L	1000	47.5	1	11	35	83	184	3.3×10^{-3}
5A-103L	1000	50.0	1	2	3	9	97	8.0×10^{-3}
5A-102L	1000	50.0	1	3	13	38	71	8.1×10^{-3}
5A-116L	1050	25.0	10	47	155	314	d	9.5×10^{-4}
5A-96L	1050	26.0	24	68	165	284	d	1.1×10^{-3}
5A-101L	1050	28.0	24	68	165	284	d	1.1×10^{-3}
5A-123L	1050	30.0	10	29	82	155	d	1.9×10^{-3}
5A-110L	1050	32.0	8	25	65	171	215	2.0×10^{-3}

a Heat No. D-8060.
b Sheet thickness: 40 mils.
c Heat treatment: 1650° F, 1/2 hr, A.C.
d Denotes that test was discontinued.

Table 60

Creep Data for the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet[a, b, c]

Specimen Number	Temp. °F	Stress, ksi	Time to creep deformation, hr 0.05%	0.1%	0.2%	0.5%	2.0%	Min. Creep Rate, % hr^{-1}
1A-122L	600	80.0	5	14	55	d	d	2.0×10^{-4}
1A-97L	600	85.0	-	8	22	65	d	1.8×10^{-4}
1A-112L	600	87.0	-	-	13	36	d	4.4×10^{-4}
1A-98L	600	90.0	1	10	15	d	d	3.4×10^{-4}
1A-111L	600	90.0	-	-	10	27	d	4.6×10^{-4}
1A-100L	600	95.0	-	-	6	10	d	3.4×10^{-4}
1A-115L	600	100.0	-	-	-	4	d	5.4×10^{-4}
1A-95L	800	44.0	13	35	210	d	d	3.1×10^{-3}
1A-117L	800	49.5	10	25	170	d	d	1.3×10^{-4}
1A-121L	800	65.0	7	17	50	990	d	1.0×10^{-4}
1A-123L	800	77.0	5	15	75	250	d	3.0×10^{-4}
1A-106L	800	77.0	-	5	27	d	d	4.5×10^{-4}
1A-116L	800	82.0	1	3	21	250	d	1.7×10^{-3}
1A-103L	800	88.0	-	2	5	28	d	1.2×10^{-3}
1A-113	900	25.0	7	18	145	440	d	7.7×10^{-4}
1A-167L	900	30.0	3	10	70	340	d	1.02×10^{-3}
1A-164L	900	35.0	3	10	42	210	1100	1.65×10^{-3}
1A-175L	900	40.0	1	3	20	165	700	2.0×10^{-3}
1A-119L	1000	5.0	40	105	185	665	d	6.8×10^{-4}
1A-104L	1000	8.0	15	31	65	201	d	1.6×10^{-3}
1A-105L	1000	10.0	10	35	80	195	885	1.4×10^{-3}
1A-99L	1000	11.5	9	18	39	114	575	3.8×10^{-3}
1A-107L	1000	13.0	5	15	35	93	500	2.7×10^{-3}
1A-94L	1000	15.0	3	6	16	65	265	6.7×10^{-3}
1A-110L	1000	15.0	4	8	21	75	340	5.8×10^{-3}

a Heat No. V-2957.
b Sheet thickness: 40 mils.
c Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, A.C.
d Denotes that test was discontinued.

Table 61

Creep Data for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet[a, b, c]

Specimen Number	Temp., °F	Stress, ksi	Time to creep deformation, hr 0.05%	0.1%	0.2%	0.5%	2.0%	Min. Cre[illegible] Rate, % h[illegible]
2A-100L	800	60.0	10	40	550	d	d	1.0 x 10[illegible]
2A-115L	800	60.0	5	30	127	d	d	5.0 x 10[illegible]
2A-102L	800	70.0	5	17	105	d	d	1.2 x 10[illegible]
2A-99L	800	78.0	5	13	55	d	d	2.6 x 10[illegible]
2A-106L	800	83.0	2	7	38	d	d	2.6 x 10[illegible]
2A-98L	800	85.0	3	5	25	310	d	4.0 x 10[illegible]
2A-109L	800	85.0	2	5	18	280	d	7.2 x 10[illegible]
2A-117L	800	88.0	–	–	2	35	d	7.4 x 10[illegible]
2A-113L	800	92.0	2	5	15	105	d	1.7 x 10[illegible]
2A-119L	900	40.0	5	20	160	d	d	2.0 x 10[illegible]
2A-107L	900	40.0	11	31	100	d	d	—
2A-120L	900	50.0	7	17	73	600	d	5.4 x 10[illegible]
2A-95L	900	55.0	3	8	21	175	d	1.3 x 10[illegible]
2A-97L	900	55.0	7	15	41	300	d	9.8 x 10[illegible]
2A-101L	900	60.0	1	3	5	105	d	1.3 x 10[illegible]
2A-116L	900	65.0	1	2	10	73	d	2.2 x 10[illegible]
2A-122L	900	65.0	1	2	10	68	d	2.9 x 10[illegible]
2A-105L	900	68.0	–	–	4	52	d	2.5 x 10[illegible]
2A-103L	1000	12.0	9	30	445	1010	d	1.6 x 10[illegible]
2A-121L	1000	16.0	7	21	135	d	d	6.4 x 10[illegible]
2A-112L	1000	20.0	4	12	55	330	980	2.0 x 10[illegible]
2A-169L	1000	20.0	3	12	60	d	d	1.0×10^{-3}
2A-96L	1000	23.0	5	15	55	220	d	1.7×10^{-3}
2A-165L	1000	25.0	2	5	20	145	d	2.2×10^{-3}
2A-94L	1000	25.0	3	8	26	190	d	1.4×10^{-3}
2A-104L	1000	25.0	3	8	26	250	d	3.3×10^{-3}
2A-111L	1000	25.0	1	2	18	290	d	5.4×10^{-4}
2A-110L	1000	30.0	1	5	15	74	435	4.1×10^{-3}

a Heat No. V-3016.
b Sheet thickness: 40 mils.
c Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.
d Denotes that test was discontinued.

Table 62

Fatigue Data for the Ti-5Al-5Sn-5Zr Alloy Sheet[a, b, c, d]

Specimen No.	Temp. °F	A	K_t	Max Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
5A-177L	70	0.67	1	100.2	60.0	188,900
5A-199L	70	0.67	1	91.9	55.0	151,300
5A-184L	70	0.67	1	83.5	50.0	1,451,400
5A-237L	70	0.67	1	80.1	48.0	5,080,700
5A-201L	70	0.67	1	78.5	47.0	3,083,000
5A-182L	70	0.67	1	78.0	46.7	3,866,700
5A-190L	70	0.67	1	76.0	45.5	4,168,590+[f]
5A-240L	70	0.67	1	76.0	45.5	1,983,200
5A-191AL	70	0.98	1	85.0	43.0	182,800
5A-178L	70	0.98	1	79.8	40.3	195,000
5A-179L	70	0.98	1	78.6	39.7	3,805,100
5A-202L	70	0.98	1	74.5	37.5	533,800
5A-192L	70	0.98	1	72.2	36.7	3,366,500
5A-191L	70	0.98	1	68.3	34.6	14,194,600+
5A-207L	400	0.67	1	85.0	50.9	181,200
5A-195L	400	0.67	1	80.0	47.9	126,200
5A-197L	400	0.67	1	80.0	47.9	804,100
5A-200L	400	0.67	1	75.0	45.0	2,561,200
5A-204L	400	0.67	1	70.0	41.9	11,132,100+
5A-209L	400	0.98	1	80.0	40.4	668,200
5A-198L	400	0.98	1	80.0	40.4	232,200
5A-193L	400	0.98	1	75.0	39.7	1,723,800
5A-194L	400	0.98	1	70.0	35.4	7,564,600
5A-180L	800	0.67	1	80.0	48.0	31,000
5A-187L	800	0.67	1	75.0	45.0	93,200
5A-183L	800	0.67	1	75.0	45.0	853,000
5A-189L	800	0.67	1	75.0	45.0	180,000
5A-185L	800	0.67	1	70.0	42.0	10,624,700+

Table 62 (Continued)

Fatigue Data for the Ti-5Al-5Sn-5Zr Alloy Sheet[a, b, c, d]

Specimen No.	Temp. °F	A	K_t	Max Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
5A-239L	800	0.98	1	70.0	35.3	173,000
5A-188L	800	0.98	1	68.0	34.4	995,500
5A-186L	800	0.98	1	65.0	32.8	3,660,000
5A-203L	800	0.98	1	60.0	30.3	3,185,000
5A-206L	800	0.98	1	50.0	25.3	10,042,800+
5A-218L	70	0.67	3	45.0	26.9	111,900
5A-217L	70	0.67	3	40.9	23.9	157,200
5A-243L	70	0.67	3	37.5	22.4	10,000,000+
5A-215L	70	0.67	3	35.0	21.0	658,900
5A-219L	70	0.67	3	30.0	17.5	10,800,000+
5A-244L	70	0.98	3	47.8	24.2	74,000
5A-213L	70	0.98	3	42.5	21.6	143,500
5A-212L	70	0.98	3	37.2	18.7	3,677,600
5A-211L	70	0.98	3	34.5	17.4	2,029,800
5A-210L	70	0.98	3	31.9	16.1	10,000,000+
5A-221L	400	0.67	3	43.0	25.8	165,800
5A-216L	400	0.67	3	40.5	17.0	99,700
5A-214L	400	0.66	3	40.5	17.0	1,012,700
5A-242L	400	0.67	3	38.0	22.7	4,370,900
5A-220L	400	0.67	3	33.0	14.4	11,900,000+
5A-228L	400	0.98	3	43.0	21.7	50,000
5A-229L	400	0.98	3	40.0	20.2	91,000
5A-236L	400	0.98	3	38.0	19.2	270,300
5A-235L	400	0.98	3	35.0	17.7	2,484,000
5A-234L	400	0.98	3	30.0	15.2	10,304,400+

Table 62 (Continued)

Fatigue Data for the Ti-5Al-5Sn-5Zr Alloy Sheet[a, b, c, d]

Specimen No.	Temp. °F	A	K_t	Max Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
5A-241L	800	0.67	3	30.0	18.0	143,900
5A-223L	800	0.67	3	30.0	18.0	162,500
5A-225L	800	0.67	3	28.0	16.7	1,464,100
5A-226L	800	0.67	3	26.0	15.5	8,954,700
5A-224L	800	0.67	3	25.0	15.0	11,570,000+
5A-233L	800	0.98	3	40.0	20.2	20,700
5A-230L	800	0.98	3	35.0	17.7	33,900
5A-231L	800	0.98	3	30.0	15.1	163,000
5A-222L	800	0.98	3	25.0	12.	4,205,800
5A-232L	800	0.98	3	20.0	10.1	10,432,000+

a Heat No. D-8060.
b Thickness: 40 mils.
c Heat treatment: 1650° F, 1/2 hr, A.C.
d All specimens from longitudinal orientation.
e Plus (+) denotes that test was discontinued.
f Shoulder failure.

Table 63

Fatigue Data for the Ti-5Al-5Zr-5Sn-1Mo-1V Sheet[a, b, c, d]

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
1A-238L	70	0.67	1	100.2	60.0	77,600
1A-237L	70	0.67	1	91.8	55.0	172,700
1A-187L	70	0.67	1	81.0	48.5	2,745,500
1A-229L	70	0.67	1	77.0	46.1	3,946,500
1A-222L	70	0.67	1	73.0	43.7	7,501,900
1A-230L	70	0.98	1	85.0	43.0	145,000
1A-240L	70	0.98	1	79.8	40.3	139,600
1A-191L	70	0.98	1	74.5	37.6	6,344,500
1A-186L	70	0.98	1	69.0	34.9	7,448,200
1A-223L	70	0.98	1	67.0	33.8	6,959,300
1A-195L	400	0.67	1	98.0	58.7	114,400
1A-192L	400	0.67	1	95.0	56.8	207,700
1A-196L	400	0.67	1	92.5	55.4	167,300
1A-239L	400	0.67	1	90.0	53.9	4,179,400
1A-241L	400	0.67	1	85.0	51.0	10,000,300+
1A-215L	400	0.98	1	79.6	40.2	47,000
1A-194L	400	0.98	1	79.6	40.2	521,400
1A-213L	400	0.98	1	77.2	39.0	805,300
1A-218L	400	0.98	1	75.0	37.8	3,516,400
1A-214L	400	0.98	1	70.3	35.5	10,000,000+
1A-242L	800	0.67	1	80.0	47.8	116,400
1A-204L	800	0.67	1	73.0	43.7	4,400,800
1A-203L	800	0.67	1	70.0	41.8	413,400
1A-219L	800	0.67	1	70.0	41.8	10,542,800+
1A-206L	800	0.67	1	65.0	39.0	10,448,100+
1A-205L	800	0.98	1	80.0	40.3	35,300
1A-231L	800	0.98	1	75.0	37.9	55,700
1A-201L	800	0.98	1	75.0	37.9	147,500
1A-202L	800	0.98	1	70.0	35.3	10,099,500+
1A-200L	800	0.98	1	65.0	32.8	10,376,300+

Table 63 (Continued)

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
1A-182L	70	0.67	3	45.0	26.9	133,900
1A-181L	70	0.67	3	45.0	26.9	146,700
1A-236L	70	0.67	3	40.0	23.9	6,048,600
1A-193L	70	0.67	3	37.5	22.5	3,751,900
1A-232L	70	0.67	3	35.0	21.9	9,568,800
1A-235L	70	0.98	3	45.0	22.7	40,000
1A-234L	70	0.98	3	45.0	22.7	47,000
1A-244L	70	0.98	3	40.0	20.2	48,300
1A-243L	70	0.98	3	38.0	19.2	11,372,400+
1A-228L	70	0.98	3	35.0	17.7	9,255,400
1A-212L	400	0.67	3	45.0	26.9	82,200
1A-226L	400	0.67	3	42.5	25.5	89,100
1A-184L	400	0.67	3	40.0	23.9	93,700
1A-225L	400	0.67	3	40.0	23.9	730,800
1A-227L	400	0.67	3	35.0	21.0	10,045,100+
1A-211L	400	0.98	3	45.0	22.7	65,000
1A-209L	400	0.98	3	42.5	21.5	69,000
1A-190L	400	0.98	3	40.0	20.2	127,000
1A-220L	400	0.98	3	40.0	20.2	1,773,100
1A-221L	400	0.98	3	37.5	18.9	8,997,100
1A-208L	800	0.67	3	45.0	26.8	90,000
1A-179L	800	0.67	3	45.0	26.8	806,700
1A-210L	800	0.67	3	40.0	24.0	130,000
1A-207L	800	0.67	3	38.0	22.7	7,980,000
1A-189L	800	0.67	3	35.0	21.0	10,600,000+
1A-180L	800	0.98	3	40.0	20.2	63,700
1A-185L	800	0.98	3	40.0	20.2	247,000
1A-188L	800	0.98	3	39.0	19.7	49,100
1A-178L	800	0.98	3	38.0	19.1	4,217,500
1A-177L	800	0.98	3	35.0	19.7	10,600,000+

a Heat No. V-2957.
b Thickness: 40 mils.
c Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
d All tests in longitudinal orientation.
e Plus (+) denotes that test was discontinued.

Table 64

Fatigue Data for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet[a, b, c, d]

Specimen No.	Temp, °F	A	K_t	Max Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
2A-209L	70	0.67	1	108.5	65.0	566,400
2A-210L	70	0.67	1	100.2	60.0	3,299,100
2A-213L	70	0.67	1	97.0	58.1	4,732,000
2A-215L	70	0.67	1	94.0	56.3	7,986,600
2A-212L	70	0.67	1	91.8	55.0	11,913,700+
2A-223L	70	0.98	1	100.0	50.5	1,058,500
2A-222L	70	0.98	1	95.0	48.0	2,886,100
2A-233L	70	0.98	1	90.0	45.4	4,357,000
2A-216L	70	0.98	1	85.0	42.9	10,498,900+
2A-221L	400	0.67	1	113.0	67.5	24,700
2A-227L	400	0.67	1	110.0	65.5	18,000
2A-224L	400	0.67	1	108.0	64.8	28,500
2A-220L	400	0.67	1	103.0	61.8	4,396,700
2A-228L	400	0.67	1	98.0	58.7	5,800,000
2A-243L	400	0.67	1	94.0	56.1	6,593,700
2A-226L	400	0.98	1	103.0	52.0	46,300
2A-225L	400	0.98	1	100.0	50.5	2,096,500
2A-230L	400	0.98	1	95.0	48.0	677,100
2A-231L	400	0.98	1	95.0	48.0	1,175,500
2A-234L	400	0.98	1	90.0	45.5	10,006,000+
2A-236L	800	0.67	1	95.0	57.0	432,200
2A-241L	800	0.67	1	90.0	53.8	237,800
2A-384L	800	0.67	1	90.0	53.8	269,200
2A-242L	800	0.67	1	85.0	50.9	1,078,500
2A-383L	800	0.67	1	80.0	48.0	11,225,000+

Table 64 (Continued)

Fatigue Data for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet[a, b, c, d]

Specimen No.	Temp, °F	A	K_t	Max Stress, ksi	Mean Stress, ksi	Cycles to Fracture[e]
2A-390L	800	0.98	1	100.0	50.5	36,400
2A-389L	800	0.98	1	95.0	48.1	136,000
2A-386L	800	0.98	1	90.0	45.5	8,400,000
2A-235L	800	0.98	1	80.0	40.4	3,150,400
2A-385L	800	0.98	1	75.0	37.9	12,000,000+
2A-198L	70	0.67	3	47.9	28.7	100,000
2A-195L	70	0.67	3	45.8	27.5	122,200
2A-196L	70	0.67	3	42.6	25.6	3,665,800
2A-197L	70	0.67	3	37.2	22.3	10,329,800+
2A-199L	70	0.98	3	42.0	21.5	55,300
2A-237L	70	0.98	3	40.0	20.2	174,000
2A-201L	70	0.98	3	38.3	19.4	5,868,100
2A-189L	70	0.98	3	37.3	18.8	10,300,000+
2A-202AL	400	0.67	3	50.0	29.9	290,600
2A-238L	400	0.67	3	47.5	28.4	66,700
2A-203L	400	0.67	3	45.0	26.9	383,900
2A-204L	400	0.67	3	42.5	25.4	3,054,900
2A-200L	400	0.67	3	41.0	24.5	5,640,000
2A-202L	400	0.67	3	40.0	24.0	10,301,300+
2A-188L	400	0.98	3	47.5	24.0	29,500
2A-206L	400	0.98	3	45.0	22.7	64,900
2A-239L	400	0.98	3	45.0	22.7	6,331,000
2A-240L	400	0.98	3	40.0	20.2	6,659,700
2A-187L	400	0.98	3	37.5	18.9	10,000,000+

Table 64 (Continued)

Fatigue Data for the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet[a, b, c, d]

Specimen No.	Temp, ° F	A	K_t	Max Stress ksi	Mean Stress, ksi	Cycles to Fracture[e]
2A-185L	800	0.67	3	45.0	27.0	22,100
2A-177L	800	0.67	3	45.0	27.0	34,200
2A-180L	800	0.67	3	44.0	26.3	31,600
2A-184L	800	0.67	3	42.5	25.5	8,016,700
2A-186L	800	0.67	3	40.0	24.0	11,339,700+
2A-183L	800	0.98	3	40.0	20.2	93,700
2A-179L	800	0.98	3	38.0	19.2	45,000
2A-181L	800	0.98	3	38.0	19.2	410,900
2A-190L	800	0.98	3	37.0	18.7	131,000
2A-182L	800	0.98	3	35.0	17.6	10,000,000+

a Heat No.: V-3016.
b Thickness: 40 mils.
c Heat treatment: 1650° F, 1/2 hr, A. C. + 1450° F, 1/4 hr, A. C.
d All specimens from longitudinal orientation.
e Plus (+) denotes that test was discontinued.

Table 65

Data for Calculation of the Stress Intensity Factor for Sheet Alloys

NOTICE

Gross yielding occurred in tests at 400 and 70° F, and to some extent at -110° F, such that the true fracture toughness is not represented by data given in this table.

Alloy	Specimen Number	Temp., °F	Gross Area	$P_{dev\text{-}lin}$[a] lb	$2a_0$ In.	K_{nc}[b] 10^4 psi $\sqrt{in.}$	σ_{net}[c] ksi	σ_{net}/F_{ty}
Ti-5Al-5Sn-5Zr	5A-377L	70	.0382	2540	.2738	4.74	91.4	0.8
	5A-376L	70	.0383	2940	.2605	5.32	103.5	0.9
	5A-378L	70	.0385	2840	.2805	5.34	102.2	0.9
	5A-379T	70	.0355	2390	.2799	4.86	93.4	0.8
	5A-381T	70	.0366	2740	.2906	5.54	105.4	0.9
	5A-380T	70	.0354	2330	.2321	4.29	85.7	0.7
	5A-381L	400	.0381	2130	.2553	3.84	75.0	1.0
	5A-380L	400	.0383	1830	.2867	3.51	66.8	0.8
	5A-384L	400	.0375	1830	.2661	3.42	66.3	0.8
	5A-382T	400	.0369	1830	.2623	3.46	67.0	0.9
	5A-385T	400	.0378	1830	.2611	3.33	65.4	0.8
	5A-384T	400	.0396	2140	.2804	3.92	75.1	1.0
	5A-383L	-110	.0374	3050	.3000	6.14	-	-
	5A-382L	-110	.0379	3050	.3020	6.08	-	-
	5A-379L	-110	.0389	3250	.2963	6.24	-	-
	5A-388T	-110	.0375	3340	.2875	6.54	-	-
	5A-383T	-110	.0397	3340	.3382	6.03	-	-
	5A-386T	-110	.0380	2640	.3402	5.63	-	-

Table 65 (Cont'd)

Alloy	Specimen Number	Temp., °F	Gross Area	$P_{dev-lin}$[a] lb	$2a_0$ In.	K_{nc}[b] 10^4 psi $\sqrt{in.}$	σ_{net}[c] ksi	σ_{net}/F_{ty}
Ti-5Al-5Sn-5Zr-1Mo-1V	1A-375L	70	.0350	2860	.2737	5.82	112.2	0.8
	1A-378L	70	.0351	2850	.2648	5.69	110.0	0.8
	1A-376L	70	.0356	2900	.2601	5.65	109.8	0.8
	1A-382T	70	.0359	2790	.2577	5.36	104.5	0.8
	1A-379T	70	.0353	2740	.2774	5.58	107.0	0.8
	1A-381T	70	.0359	3040	.2596	5.87	114.3	0.8
	1A-382L	400	.0369	2440	.2800	4.77	91.7	0.9
	1A-381L	400	.0362	2030	.2773	4.03	88.9	0.8
	1A-384L	400	.0365	2340	.2702	4.55	87.6	0.8
	1A-385T	400	.0376	2440	.2882	4.77	91.0	0.9
	1A-387T	400	.0373	2650	.2564	4.90	95.3	0.9
	1A-386T	400	.0376	2340	.2505	4.23	83.0	0.8
	1A-379L	-110	.0370	3050	.3559	6.89	-	-
	1A-380L	-110	.0374	3050	.2916	6.04	-	-
	1A-377L	-110	.0343	3240	.2588	6.53	-	-
	1A-383T	-110	.0374	3050	.2607	5.66	-	-
	1A-388T	-110	.0370	2540	.2911	5.07	-	-
	1A-380T	-110	.0358	2540	.2758	5.09	-	-
Ti-6Al-2Sn-4Zr-2Mo	2A-376L	70	.0406	3600	.2413	5.90	116.5	0.8
	2A-377L	70	.0407	3350	.2660	5.78	112.0	0.8
	2A-378L	70	.0404	3450	.2711	6.06	116.9	0.8
	2A-382T	70	.0411	3240	.3220	6.20	116.1	0.8
	2A-379T	70	.0409	2540	.3151	4.82	90.4	0.6
	2A-380T	70	.0410	3460	.2490	5.72	112.3	0.8
	2A-384L	400	.0412	3050	.2495	5.02	98.4	0.9
	2A-383L	400	.0410	2850	.2958	5.19	98.6	0.9
	2A-380L	400	.0400	2540	.2560	4.38	85.2	0.8
	2A-393T	400	.0413	2540	.2590	4.26	82.7	0.8
	2A-394T	400	.0408	2340	.2769	4.13	79.0	0.8
	2A-391T	400	.0413	2410	.2614	4.07	78.7	0.8

Table 65 (Cont'd)

Alloy	Specimen Number	Temp., °F	Gross Area	$P_{dev-lin}$[a] lb	$2a_0$ in.	K_{nc}[b] 10^4 psi $\sqrt{in.}$	σ_{net}[c] ksi	$\frac{\sigma_{net}}{F_{ty}}$
Ti-6Al-2Sn-4Zr-2Mo	2A-379L	-110	.0408	3560	.2710	6.19	–	–
	2A-381L	-110	.0417	3560	.2763	6.12	–	–
	2A-382L	-110	.0418	3870	.2806	6.70	–	–
	2A-381T	-110	.0411	3560	.2856	6.34	–	–
	2A-395T	-110	.0404	3450	.2850	6.25	–	–
	2A-392T	-110	.0416	3260	.3254	6.19	–	–

a Load at deviation in linearity in compliance-gage-output vs load curve.

b Stress intensity factor reported as K_{nc}, rather than K_{Ic}, because pop-in was not observed and calculations were based on load at deviation from linearity.

c Calculated from load at deviation from linearity.

Table 66

Data for Calculation of the Apparent K_c for Sheet Alloys

NOTICE

Gross yielding occurred in tests at 400 and 70° F, and to some extent at -110° F, such that the true fracture toughness is not represented by data given in this table.

Alloy	Specimen Number	Temp., ° F	Gross Area	P_{max} lb	σ max ksi	V_o 10^{-3}	$2a_o$ In.	V_f 10^{-3}	K_c[a] ksi $\sqrt{in.}$	σ net[b] ksi	$\frac{\sigma \text{ net}}{F_{ty}}$
Ti-5Al-5Sn-5Zr	5A-377L	70	.0382	3460	90.57	6.45	.2738	9.40	x	124.5	1.0
	5A-376L	70	.0383	3290	85.90	6.76	.2605	10.10	x	115.8	1.0
	5A-378L	70	.0385	3220	83.63	6.83	.2805	9.56	x	115.8	1.0
	5A-379T	70	.0355	2975	83.80	5.98	.2799	9.36	x	116.2	1.0
	5A-381T	70	.0366	3180	86.88	6.25	.2906	8.90	x	122.3	1.0
	5A-380T	70	.0354	2975	84.04	6.05	.2321	9.37	x	109.4	0.9
	5A-381L	400	.0381	2610	68.50	5.47	.2553	11.70	x	91.9	1.2
	5A-380L	400	.0383	2480	64.75	5.47	.2867	11.70	x	90.5	1.1
	5A-384L	400	.0375	2450	65.33	5.74	.2661	11.28	x	88.7	1.1
	5A-382T	400	.0369	2460	66.67	5.47	.2628	13.10	x	90.1	1.1
	5A-385T	400	.0378	2570	67.99	5.35	.2611	12.30	x	91.7	1.1
	5A-384T	400	.0396	2580	65.15	5.39	.2804	13.65	x	90.5	1.1
	5A-383L	-110	.0374	3670	98.13	7.11	.3000	8.98	120.9	-	-
	5A-382L	-110	.0379	3720	98.15	7.00	.3020	8.55	113.8	-	-
	5A-379L	-110	.0389	3970	102.06	7.35	.2963	9.18	119.9	-	-
	5A-388T	-110	.0375	3840	102.67	6.95	.2875	9.38	136.9	-	-
	5A-383T	-110	.0397	3880	97.73	6.53	.3382	8.59	123.1	-	-
	5A-386T	-110	.0380	3560	93.68	6.17	.3402	7.81	117.2	-	-

Table 66 (Cont'd)

Alloy	Specimen Number	Temp., °F	Gross Area	P_{max} lb	σ_{max} ksi	V_o 10^{-3}	$2a_o$ In.	V_f 10^{-3}	K_c[a] ksi $\sqrt{in.}$	σ_{net}[b] ksi	$\frac{\sigma_{net}}{F_{ty}}$
Ti-5Al-5Sn-5Zr-1Mo-1V	1A-375L	70	.0350	3120	89.14	7.30	.2737	8.40	92.4	122.3	0.9
	1A-378L	70	.0351	3310	94.30	7.42	.2648	8.90	105.5	127.8	0.9
	1A-376L	70	.0356	3310	92.98	7.23	.2601	8.40	94.6	125.4	0.9
	1A-382T	70	.0359	3500	97.49	6.87	.2577	8.00	97.2	131.1	1.0
	1A-379T	70	.0353	3260	92.35	6.84	.2774	8.11	100.3	127.3	0.9
	1A-381T	70	.0359	3530	98.33	7.04	.2596	8.01	89.3	132.7	1.0
	1A-382L	400	.0369	2810	76.15	6.56	.2800	8.40	x	105.6	1.0
	1A-381L	400	.0362	2720	75.14	6.17	.2773	8.05	x	103.8	1.0
	1A-384L	400	.0365	2870	78.63	6.72	.2702	8.67	x	107.5	1.0
	1A-385T	400	.0376	2860	76.06	6.49	.2882	8.45	x	106.7	1.0
	1A-387T	400	.0373	3020	80.96	6.76	.2564	9.14	x	108.6	1.0
	1A-386T	400	.0376	3170	84.31	6.16	.2505	8.40	x	112.4	1.0
	1A-379L	-110	.0370	3480	94.05	6.60	.3559	8.10	104.7	-	-
	1A-380L	-110	.0374	3750	100.26	6.72	.2916	8.60	121.3	-	-
	1A-377L	-110	.0343	3730	108.75	7.82	.2588	8.66	101.0	-	-
	1A-383T	-110	.0374	4050	108.29	6.99	.2607	8.60	119.2	-	-
	1A-388T	-110	.0370	3670	99.19	6.45	.2911	7.50	102.8	-	-
	1A-380T	-110	.0358	3630	101.40	6.48	.2758	7.62	101.8	-	-

Table 66 (Cont'd)

Alloy	Specimen Number	Temp., °F	Gross Area	P_{max} lb	σ max lb	V_o 10^{-3}	$2a_o$ In.	V_f 10^{-3}	K_c[a] ksi $\sqrt{in.}$	σ net[b] ksi	σ net / F_{ty}
Ti-6Al-2Sn-4Zr-2Mo	2A-376L	70	.0406	4250	104.68	7.12	.2413	8.40	108.2	137.5	1.0
	2A-377L	70	.0407	4040	99.26	6.84	.2660	8.20	106.1	135.1	1.0
	2A-378L	70	.0404	4070	100.74	7.12	.2711	8.40	105.2	137.9	1.0
	2A-382T	70	.0411	3790	92.21	6.72	.3220	7.80	99.4	135.8	1.0
	2A-379T	70	.0409	3710	90.71	6.45	.3151	7.62	99.9	132.0	1.0
	2A-380T	70	.0410	4120	100.49	7.35	.2490	8.40	99.9	133.8	1.0
	2A-384L	400	.0412	3540	85.92	7.10	.2495	12.50	x	114.2	1.0
	2A-383L	400	.0410	3210	78.29	7.03	.2958	12.28	x	111.1	1.0
	2A-380L	400	.0400	3410	85.25	6.56	.2560	10.00	x	114.4	1.0
	2A-393T	400	.0413	3480	84.26	6.45	.2590	10.80	x	113.4	1.0
	2A-394T	400	.0408	3240	79.41	6.45	.2769	8.60	x	109.5	1.0
	2A-391T	400	.0413	3400	82.32	6.56	.2614	11.52	x	111.1	1.0
	2A-379L	-110	.0408	4500	110.29	7.38	.2710	8.40	105.2	-	-
	2A-381L	-110	.0417	4680	112.23	7.62	.2763	9.15	122.0	-	-
	2A-382L	-110	.0418	4670	111.72	7.55	.2806	8.86	115.8	-	-
	2A-381T	-110	.0411	4280	104.00	7.42	.2856	8.48	105.5	-	-
	2A-395T	-110	.0404	4220	104.45	7.50	.2850	8.66	108.1	-	-
	2A-392T	-110	.0416	4140	99.52	7.03	.3254	8.40	110.2	-	-

a "x" denotes that K_c could not be calculated because of extensive slow-crack growth.
b Calculated from maximum load.

Table 67

Average Tensile Properties of the Ti-5Al-5Sn-5Zr Alloy Sheet after Dry-Salt Stress Corrosion at Different Stresses, Temperatures, and Times[a, b]

Exposure Conditions			Room-Temperature Tensile Properties After Exposure		
Temp, °F	Time, hr	Stress, % of F_{ty}	F_{ty}, ksi	F_{tu}, ksi	e, %
- Unexposed -			118.6	128.5	14
600	10	60	116.8	126.1	16
600	10	80	112.8	125.9	14
600	100	40	116.3	126.5	14
600	100	60	118.4	128.1	4
600	1000	40	110.3	117.5	4
700	10	60	109.3	121.0	6
700	10	80	109.6	121.0	5
700	100	40	108.0	111.6	2
700	100	60	110.6	118.3	6
700	1000	40	74.0	76.8	1
800	10	60	104.6	114.1	4
800	10	80	108.0[c]	103.8[c]	2
800	100	40	—[d]	71.8	0
800	100	60	Failed during stress-corrosion exposure		
900	10	60	94.7[c]	78.2[c]	0
900	10	80	94.4[c]	84.9[c]	0
900	100	40	Failed during stress-corrosion exposure		
900	100	60	Failed during stress-corrosion exposure		

a 40 mil sheet. Heat No. D-8060.

b Heat treatment: 1650° F, 1/2 hr, A.C.

c The reported value for F_{ty} if high relative to F_{tu} because one of the duplicate specimens fractured before the 0.2% offset. Value shown for F_{ty} is for one specimen whereas reported F_{tu} is average for duplicate tests.

d One specimen fractured during stress-corrosion exposure. The duplicate specimen fractured in the tensile test after exposure before 0.2% offset.

Table 88

Average Tensile Properties of the Ti-5Al-5Sn-5Zr-1Mo-1V Alloy Sheet After Dry-Salt Stress Corrosion Exposure at Different Stresses, Temperatures, and Times[a, b]

Exposure Conditions			Room-Temperature Tensile Properties After Exposure		
Temp, °F	Time, hr	Stress, % of F_{ty}	F_{ty}, ksi	F_{tu}, ksi	e, %
- Unexposed -			136.8	146.8	11
500	10	60	131.0	152.4	10
500	10	80	126.0	151.0	10
500	100	40	143.3	159.0	10
500	100	60	134.6	159.5	10
500	1000	40	141.0	159.5	8
600	10	60	132.2	155.0	10
600	10	80	126.8	156.8	10
600	100	40	142.8	157.7	10
600	100	60	142.2	161.8	8
600	1000	40	—[c]	84.7	0
700	10	60	132.0	158.5	9
700	10	80	127.1	155.5	3
700	100	40	146.0	168.2	8
700	100	60	139.5[d]	127.3[d]	4
800	10	60	139.6[d]	132.5[d]	0.5
800	10	80	135.5[d]	142.4[d]	1
800	100	40	—[c]	110.0	1
800	100	60	134.9	154.1	2

a 40 mil sheet, Heat V-2957
b Heat treatment: 1550° F, 1/2 hr, A.C. + 1400° F, 1/4 hr, A.C.
c Fractured before the 0.2% offset.
d The reported value for F_{ty} if high relative to F_{tu} because one of the duplicates fractured before the 0.2% offset. Value shown for F_{ty} is for one specimen whereas reported F_{tu} is average for duplicate tests.

Table 69

Average Tensile Properties of the Ti-6Al-2Sn-4Zr-2Mo Alloy Sheet after Dry-Salt Stress Corrosion Exposure at Different Stresses, Temperatures, and Times[a, b]

Exposure Conditions			Room-Temperature Tensile Properties After Exposure		
Temp, °F	Time, hr	Stress, % of F_{ty}	F_{ty}, ksi	F_{tu}, ksi	e, %
- Unexposed -			142.2	147.7	12
500	10	60	138.0	149.2	12
500	10	80	133.5	149.8	12
500	100	40	149.1	155.0	12
500	100	60	139.6	151.6	12
500	1000	40	144.8	154.8	13
600	10	60	138.0	153.0	11
600	10	80	131.2	155.4	6
600	100	40	141.8	152.4	10
600	100	60	136.8	153.4	6
600	1000	40	—[c]	94.7	0
700	10	60	132.2	154.4	7
700	10	80	128.4	152.5	6
700	100	40	144.2	157.8	8
700	100	60	138.3	156.9	4
800	10	60	135.2	147.9	3
800	10	80	127.0	130.1	1
800	100	40	138.7	148.2	4
800	100	60	—[d]	117.5	0

a 40 mil sheet, Heat No. V-3016
b Heat treatment: 1650° F, 1/2 hr, A.C. + 1450° F, 1/4 hr, A.C.
c Fractured before 0.2% offset.
d One specimen fractured during stress-corrosion exposure. The duplicate specimen fractured in the tensile test after exposure before 0.2% offset.

Table 70

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Bar from Heat No. D-8060 at Different Temperatures[a,b]

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
5A-1	75	122.1	132.1	16	42	17.1
5A-8	75	124.2	133.2	15	40	16.8
5A-12	75	122.0	130.0	17	38	15.9
5A-15	75	121.7	130.0	15	39	15.9
5A-18	75	121.8	129.5	16	38	16.7
5A-23	75	121.0	129.0	17	40	16.6
5A-25	75	122.0	129.2	17	33	16.1
5A-40	75	122.0	130.0	17	38	17.5
5A-43	75	122.1	129.8	15	38	16.0
5A-56	75	120.8	128.5	15	40	16.3
5A-2	400	80.7	95.9	18	47	15.0
5A-14	400	81.0	95.5	19	42	15.4
5A-17	400	81.0	94.0	20	46	16.9
5A-26	400	79.0	94.1	21	47	13.9
5A-32	400	80.0	94.1	20	42	16.6
5A-34	400	81.0	95.3	20	45	15.1
5A-37	400	80.0	95.0	24	43	15.1
5A-41	400	81.0	95.5	21	45	14.6
5A-48	400	81.0	95.0	20	44	16.1
5A-53	400	80.0	93.2	22	45	15.5
5A-3	600	68.4	86.1	17	50	17.4
5A-7	600	71.5	88.0	18	40	14.2
5A-9	600	67.8	86.8	21	43	14.0
5A-13	600	68.5	87.2	20	44	13.0
5A-19	600	67.1	85.1	23	49	17.5
5A-28	600	65.7	85.6	23	47	13.8
5A-33	600	66.9	85.9	23	46	14.9
5A-42	600	66.4	86.2	22	46	12.6
5A-47	600	67.2	86.3	22	46	14.2
5A-52	600	68.7	84.9	22	47	14.7
5A-4	800	63.3	80.7	26	54	13.2
5A-16	800	61.7	81.3	27	49	13.7
5A-21	800	60.0	78.8	29	52	13.2
5A-24	800	57.5	80.0	29	53	14.0
5A-27	800	60.8	80.3	30	48	13.3
5A-31	800	59.4	79.7	20	50	13.8
5A-35	800	60.8	80.3	29	50	12.0
5A-44	800	56.8	80.5	26	50	12.0
5A-49	800	58.8	79.5	29	52	14.2
5A-55	800	59.3	78.4	30	52	14.0

Table 70 (Continued)

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
5A-10	1000	58.8	75.9	24	49	11.4
5A-11	1000	60.4	76.5	23	49	11.9
5A-20	1000	57.9	75.5	23	54	12.4
5A-30	1000	58.3	75.7	23	51	12.4
5A-36	1000	57.8	75.3	23	51	12.0
5A-39	1000	58.8	76.3	24	51	12.4
5A-45	1000	58.5	76.9	21	52	11.5
5A-46	1000	59.2	76.5	22	51	11.4
5A-50	1000	57.2	75.1	24	51	12.5
5A-51	1000	54.3	74.4	21	53	10.6

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650° F, 2 hr, A. C.

Table 71

Tensile Properties of Ti-5Al-5Sn-5Zr Alloy Bar from Heat No. D-1793 at Different Temperatures[a, b]

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
5B-1	75	113.0	120.0	18	40	16.4
5B-8	75	118.0	123.0	17	38	16.5
5B-11	75	116.0	122.0	17	40	16.8
5B-16	75	116.0	123.0	19	39	16.4
5B-24	75	117.0	122.0	19	40	16.7
5B-27	75	116.0	123.0	16	40	16.8
5B-35	75	117.0	123.0	16	41	16.6
5B-42	75	117.0	123.0	16	41	16.4
5B-48	75	118.0	124.0	16	41	16.5
5B-51	75	117.0	124.0	17	41	16.9
5B-2	400	82.0	95.8	22	47	13.8
5B-5	400	81.8	95.7	21	45	16.6
5B-14	400	81.1	95.0	21	46	16.6
5B-17	400	80.6	95.5	21	45	15.2
5B-28	400	80.9	95.4	21	46	17.2
5B-32	400	80.9	95.7	22	46	16.7
5B-39	400	81.0	95.0	21	45	15.8
5B-43	400	81.8	96.2	21	46	17.1
5B-47	400	81.7	95.7	22	45	19.3
5B-54	400	81.3	95.6	21	47	19.0
5B-3	600	67.3	87.4	23	49	13.9
5B-10	600	67.6	88.1	23	49	16.9
5B-13	600	68.5	88.5	23	48	14.5
5B-20	600	68.5	88.3	23	48	15.6
5B-23	600	67.7	87.8	23	49	13.8
5B-30	600	67.7	81.9	23	49	13.8
5B-31	600	67.7	87.9	24	50	14.8
5B-33	600	67.2	87.1	23	49	14.3
5B-45	600	66.6	86.7	24	50	14.5
5B-52	600	67.7	87.9	24	50	13.2
5B-4	800	61.7	82.2	28	51	14.8
5B-7	800	61.8	81.7	27	53	13.8
5B-18	800	61.6	81.3	28	52	13.5
5B-19	800	61.7	81.8	27	53	15.0
5B-29	800	61.3	81.3	28	51	14.2
5B-34	800	61.8	81.4	27	53	13.8
5B-41	800	60.8	80.8	27	52.	13.8
5B-46	800	61.6	81.3	27	52	13.6
5B-49	800	61.7	80.5	27	52	17.1
5B-53	800	62.1	82.0	27	53	15.4

Table 71 (Continued)

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
5B-6	1000	59.3	77.8	22	52	11.7
5B-9	1000	59.8	77.0	23	54	13.0
5B-12	1000	60.0	77.4	22	53	12.9
5B-15	1000	60.2	78.4	22	53	11.6
5B-21	1000	59.2	77.8	23	52	10.4
5B-22	1000	59.3	77.8	23	51	11.1
5B-25	1000	60.2	77.7	23	53	11.5
5B-26	1000	60.2	78.0	24	52	13.4
5B-33	1000	59.9	77.8	23	53	12.8
5B-50	1000	60.5	77.7	22	52	12.4

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650°F, 2 hr, A. C.

Table 72

Tensile Properties of Ti-679 Alloy Bar from Heat No. D-7274 at Different Temperatures[a, b]

Specimen No.	Temp., °F	Fty ksi	Ftu ksi	e %	R. A. %	E_t 10^6 psi
9A-1	75	140.0	150.0	15	44	15.3
9A-5	75	134.0	149.0	14	44	15.2
9A-9	75	138.0	149.0	15	45	15.6
9A-41	75	138.0	146.0	15	46	15.1
9A-55	75	140.0	149.0	14	44	15.0
9A-107	75	140.0	150.0	14	45	15.0
9A-115	75	137.0	146.0	15	39	15.3
9A-121	75	137.0	146.0	14	41	14.6
9A-129	75	142.0	151.0	14	40	15.6
9A-133	75	140.0	150.0	14	41	15.6
9A-13	400	103.0	124.0	16	49	14.4
9A-17	400	102.0	124.0	17	50	15.6
9A-59	400	103.0	124.0	15	50	14.4
9A-63	400	102.0	122.0	15	45	14.5
9A-108	400	100.0	121.0	17	51	13.6
9A-113	400	100.0	122.0	16	51	12.9
9A-116	400	96.8	118.0	17	48	14.8
9A-122	400	96.3	118.0	16	47	15.0
9A-130	400	99.0	120.0	14	48	15.6
9A-134	400	101.0	122.0	14	49	15.1
9A-29	600	88.7	115.0	14	46	13.0
9A-33	600	90.8	114.0	13	51	13.8
9A-53	600	90.1	114.0	15	51	14.4
9A-67	600	90.9	116.0	14	48	13.3
9A-71	600	90.5	115.0	13	50	14.4
9A-109	600	91.0	116.0	15	56	12.7
9A-117	600	87.5	112.0	14	47	14.2
9A-123	600	87.8	112.0	14	44	13.1
9A-131	600	92.6	116.0	13	46	14.3
9A-135	600	86.0	111.0	14	50	13.8
9A-21	800	82.1	110.0	16	48	13.6
9A-25	800	84.0	110.0	14	51	13.1
9A-75	800	85.6	110.0	16	49	12.8
9A-79	800	82.5	110.0	14	49	13.3
9A-83	800	84.9	110.0	15	51	13.6
9A-110	800	80.1	108.0	17	52	12.7
9A-118	800	82.5	106.0	15	49	13.0
9A-124	800	81.0	106.0	16	45	13.3
9A-132	800	84.7	110.0	15	47	13.8
9A-136	800	83.5	108.0	16	51	13.3

Table 72 (Continued)

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
9A-37	1000	78.2	99.5	17	61	13.0
9A-45	1000	78.5	101.0	19	62	13.3
9A-87	1000	79.1	101.0	18	61	12.8
9A-91	1000	79.5	101.0	17	[illegible]	11.8
9A-111	1000	80.0	103.0	17	55	11.8
9A-112	1000	75.6	99.5	17	57	11.0
9A-119	1000	76.1	97.9	17	54	11.9
9A-125	1000	76.0	99.1	17	51	12.2
9A-126	1000	73.7	96.2	17	53	12.5
9A-127	1000	77.6	98.6	17	52	12.6

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650°F, 2 hr, A. C. + 930°F, 24 hr, A. C.

Table 73

Tensile Properties of Ti-679 Alloy Bar from Heat No. D-8427 at Different Temperatures[a, b]

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
9B-1	75	133.0	145.0	13	38	15.1
9B-8	75	132.0	142.5	12	40	15.5
9B-11	75	132.0	143.2	12	43	15.4
9B-16	75	131.3	143.0	12	44	15.4
9B-24	75	128.0	140.7	13	44	15.2
9B-27	75	129.5	141.0	12	46	15.2
9B-35	75	130.5	142.0	12	45	15.2
9B-42	75	131.5	143.5	12	42	15.4
9B-48	75	128.4	142.5	12	42	15.3
9B-51	75	134.0	145.5	12	40	15.2
9B-2	400	99.2	119.0	14	50	14.6
9B-5	400	91.8	118.0	15	46	14.4
9B-14	400	96.9	116.0	14	50	13.8
9B-17	400	93.0	117.0	13	46	13.9
9B-28	400	95.2	114.0	14	51	13.4
9B-32	400	96.2	115.0	14	50	15.3
9B-39	400	96.2	116.0	13	50	14.1
9B-43	400	95.2	116.0	14	52	13.9
9B-47	400	99.6	119.0	13	46	13.4
9B-54	400	97.2	117.0	14	46	14.0
9B-3	600	86.8	110.0	13	41	14.2
9B-10	600	88.8	111.0	12	46	14.6
9B-13	600	88.8	108.0	13	49	14.6
9B-20	600	84.9	108.0	13	49	13.7
9B-23	600	85.0	107.0	13	48	13.6
9B-30	600	81.6	106.0	13	52	13.2
9B-31	600	83.9	106.0	14	52	14.4
9B-38	600	85.0	108.0	14	48	14.1
9B-45	600	86.5	110.0	13	48	13.3
9B-52	600	85.7	109.0	13	49	13.3
9B-4	800	84.8	106.0	13	47	12.9
9B-7	800	83.4	107.0	14	44	13.0
9B-18	800	82.3	105.0	14	51	13.0
9B-19	800	80.0	103.0	15	53	12.3
9B-29	800	80.3	103.0	17	53	12.9
9B-34	800	79.9	103.0	15	56	13.2
9B-41	800	80.1	104.0	15	52	13.4
9B-46	800	78.3	102.5	14	50	13.2
9B-49	800	82.5	106.0	13	50	13.7
9B-53	800	84.0	107.0	13	47	13.2

Table 73 (Continued)

Specimen No.	Temp., °F	F_{ty} ksi	F_{tu} ksi	e %	R. A. %	E_t 10^6 psi
9B-6	1000	77.5	99.0	14	51	12.6
9B-9	1000	74.4	98.0	15	51	13.0
9B-12	1000	75.2	98.7	16	55	12.9
9B-15	1000	74.3	97.5	16	55	12.3
9B-21	1000	73.0	95.8	16	57	13.4
9B-22	1000	71.7	95.6	16	57	12.8
9B-25	1000	74.8	96.5	15	53	12.1
9B-26	1000	74.8	97.2	15	50	10.4
9B-33	1000	73.9	96.7	16	55	10.9
9B-50	1000	70.8	97.2	16	59	12.3

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650°F, 2 hr, A. C. + 930°F, 24 hr, A. C.

Table 74

Notched Tensile Properties of the Bar Alloys[a, b, c]

Alloy	Specimen No.	Temp., °F	Notched Tens. Str., ksi
Ti-5Al-5Sn-5Zr	5A-29	70	200.0
	5A-114	70	197.9
	5A-38	400	137.6
	5A-102	400	143.7
	5A-6	800	115.3
	5A-22	800	116.0
Ti-679	9A-95	70	219.8
	9A-128	70	217.6
	9A-99	400	178.6
	9A-120	400	172.6
	9A-47	800	162.0
	9A-48	800	167.[illegible]

a Section size: 1/2 in. x 1-1/8 in.

b Heat treatment:

Ti-679, 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

Ti-5Al-5Sn-5Zr, 1650° F, 2 hr, A.C.

c Notched 45°, 0.010 in. radius, 0.187 minimum diameter to produce $K_t = 3$

Table 75

Compression Properties of Ti-5Al-5Sn-5Zr Alloy Bar at Different Temperatures[a, b, c]

Temp., °F	Specimen Number	F_{cy} ksi	E_c 10^6 psi
70	5A-244	128.5	15.6
70	5A-243	121.5	15.3
70	5A-236	129.1	15.3
70	5A-225	128.3	14.9
70	5A-245	127.0	15.7
400	5A-227	90.4	14.0
400	5A-247	86.0	14.2
400	5A-238	83.6	14.1
400	5A-229	86.3	14.2
400	5A-220	88.2	14.5
600	5A-231	71.7	13.2
600	5A-222	77.7	13.6
600	5A-242	72.8	13.2
600	5A-233	70.7	13.4
600	5A-224	74.7	12.9
800	5A-235	63.5	12.3
800	5A-226	69.5	12.3
800	5A-246	65.1	12.9
800	5A-237	64.6	12.7
800	5A-228	61.3	12.7
1000	5A-239	63.6	11.8
1000	5A-230	62.3	11.8
1000	5A-221	68.6	12.1
1000	5A-241	64.3	11.2
1000	5A-232	62.7	12.1

a Heat No. D-8060.

b Section size: 1-1/8 in. x 1/2 in.

c Heat treatment: 1650° F, 2 hr, A.C.

Table 76

Compression Properties of Ti-679 Alloy Bar at Different Temperatures[a, b, c]

Temp., °F	Specimen Number	F_{cy} ksi	E_c 10^6 psi
70	9A-228	142.9	14.7
70	9A-211	138.4	14.3
70	9A-217	139.5	14.2
70	9A-223	140.8	14.5
70	9A-229	139.3	14.6
400	9A-206	110.5	14.2
400	9A-212	100.5	13.6
400	9A-218	102.5	14.0
400	9A-224	105.5	13.7
400	9A-230	103.2	13.7
600	9A-207	92.8	12.7
600	9A-213	92.8	12.7
600	9A-219	92.7	12.3
600	9A-225	95.0	13.2
600	9A-231	93.3	13.2
800	9A-208	86.5	12.1
800	9A-214	85.3	12.3
800	9A-220	87.0	12.1
800	9A-226	89.4	12.1
800	9A-232	87.0	12.1
1000	9A-209	79.6	11.2
1000	9A-215	78.6	11.5
1000	9A-221	80.2	11.4
1000	9A-227	81.0	12.1
1000	9A-233	81.4	11.4

a Heat No. D-7274.
b Section size: 1/2 in. x 1-1/8 in.
c Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

Table 77

Ultimate Shear Strength of Ti-5Al-5Sn-5Zr Alloy Bar from Heat No. D-8060 at Different Temperatures[a, b]

70°F		400°F		600°F		800°F		1000°F	
Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi
5A-248	99.2	5A-249	75.0	5A-250	70.3	5A-251	66.8	5A-253	61.9
5A-256	104.2	5A-257	75.0	5A-258	73.2	5A-252	65.8	5A-261	61.6
5A-264	102.3	5A-265	77.1	5A-259	67.4	5A-260	65.8	5A-269	61.7
5A-272	99.8	5A-266	79.0	5A-267	67.3	5A-268	63.2	5A-277	61.0
5A-273	109.0	5A-274	77.6	5A-275	71.9	5A-276	65.1	5A-278	61.6

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650°F, 2 hr, A.C.

Table 78

Ultimate Shear Strength of Ti-679 Alloy Bar from Heat No. D-7242 at Different Temperatures[a, b]

70°F		400°F		600°F		800°F		1000°F	
Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi	Specimen No.	F_{su} ksi
9A-235	102.5	9A-236	81.5	9A-237	80.3	9A-241	77.6	9A-240	72.7
9A-243	107.5	9A-244	88.5	9A-245	82.7	9A-239	77.4	9A-248	70.7
9A-251	110.0	9A-252	82.1	9A-246	81.6	9A-247	74.9	9A-256	73.6
9A-259	110.0	9A-253	85.9	9A-254	78.6	9A-255	77.7	9A-264	76.5
9A-260	102.4	9A-261	90.0	9A-262	80.7	9A-263	79.3	9A-265	70.1

[a] Section size: 1/2 in. x 1-1/8 in.
[b] Heat treatment: 1650°F, 2 hr, A.C. + 930°F, 24 hr, A.C.

Table 79

Rockwell C Hardness of Bar Alloys After Exposure at Different Temperatures and Times

Exposure Temp., ° F	Exposure Time, hr	R_C Hardness Ti-5Al-5Sn-5Zr[a, b]	Ti-679[a, b]
RT	-	31.5	35.6
600	1000	31.0	36.3
800	100	31.6	38.5
800	1000	32.5	36.4
1000	10	31.1	37.8
1000	100	32.5	37.2
1000	1000	32.0	36.8
1100	10	30.4	36.9
1150	10	32.5	37.0
1200	10	31.6	35.7

a Section size: 1/2 in. x 1-1/8 in.

b Heat treatments:

Ti-5Al-5Sn-5Zr bar, 1650° F, 2 hr, A.C.

Ti-679, 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

Table 80

Tensile Properties of the Ti-5Al-5Sn-5Zr Alloy Bar at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b, c]

Exposure Conditions		F_{ty}, ksi						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	122.0						
600	0.25	-	67.8					
600	1000	121.9	69.4					
800	0.25	-	-	59.8				
800	100	124.4	-	62.1				
800	1000	128.9	-	65.2				
1000	0.25	-	-	-	58.1			
1000	10	125.0	-	-	59.0			
1000	100	128.0	-	-	59.9			
1000	1000	128.0	-	-	60.0			
1100	10	122.8	-	-	-	56.2		
1150	10	122.5	-	-	-	-	55.3	
1200	10	123.4	-	-	-	-	-	50.3

Exposure Conditions		F_{tu}, ksi						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	130.1						
600	0.25	-	88.2					
600	1000	129.3	89.0					
800	0.25	-	-	79.9				
800	100	131.6	-	80.5				
800	1000	133.9	-	83.6				
1000	0.25	-	-	-	75.8			
1000	10	131.0	-	-	75.6			
1000	100	134.5	-	-	76.4			
1000	1000	135.0	-	-	78.6			
1100	10	130.8	-	-	-	76.8		
1150	10	130.2	-	-	-	-	75.8	
1200	10	131.6	-	-	-	-	-	69.6

Table 80 (Cont'd)

Tensile Properties of the Ti-5Al-5Sn-5Zr Alloy Bar at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b, c]

Exposure Conditions		e, %						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
70	-	16						
600	0.25	-	21					
600	1000	17	22					
800	0.25	-	-	28				
800	100	16	-	28				
800	1000	12	-	27				
1000	0.25	-	-	-	23			
1000	10	14	-	-	22			
1000	100	12	-	-	21			
1000	1000	12	-	-	22			
1100	10	16	-	-	-	21		
1150	10	16	-	-	-	-	29	
1200	10	16	-	-	-	-	-	39

Exposure Conditions		R.A., %						
Temp.	Time	Test Temperature, °F						
°F	Hr	70	600	800	1000	1100	1150	1200
39	-	39						
600	0.25	-	47					
600	1000	42	43					
800	0.25	-	-	51				
800	100	41	-	52				
800	1000	20	-	49				
1000	0.25	-	-	-	51			
1000	10	37	-	-	52			
1000	100	32	-	-	49			
1000	1000	31	-	-	49			
1100	10	38	-	-	-	50		
1150	10	38	-	-	-	-	48	
1200	10	40	-	-	-	-	-	45

a. Heat treatment: 1650° F, 2 hr, A.C.

b. Section: 1/2 in. x 1-1/8 in.

c. Results are averages of duplicate tests except those for single specimens exposed and tested at 1100, 1150, and 1200° F.

Table 81

Tensile Properties of the Ti-679 Alloy Bar at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b, c]

Exposure Conditions		F_{ty}, ksi						
Temp., °F	Time Hr	Test Temperature, °F: 70	600	800	1000	1100	1150	1200
70	-	138.6	89.8					
600	0.25	-	89.8					
600	1000	139.1	94.1					
800	0.25	-	-	83.1				
800	100	137.0		88.2				
800	1000	141.4	-	86.9				
1000	0.25	-	-	-	77.4			
1000	10	137.5	-	-	81.6			
1000	100	138.0	-	-	80.2			
1000	1000	143.5	-	-	78.3			
1100	10	138.1	-	-	-	70.8		
1150	10	137.7	-	-	-	-	66.2	
1200	10	137.4	-	-	-	-	-	59.2

Exposure Conditions		F_{tu}, ksi						
Temp., °F	Time Hr	Test Temperature, °F: 70	600	800	1000	1100	1150	1200
70	-	148.6						
600	0.25	-	114.1					
600	1000	149.9	118.0					
800	0.25	-	-	108.8				
800	100	148.2	-	111.9				
800	1000	149.4	-	111.8				
1000	0.25	-	-	-	99.7			
1000	10	147.0	-	-	104.5			
1000	100	149.0	-	-	102.5			
1000	1000	149.0	-	-	96.6			
1100	10	145.2	-	-	-	88.1		
1150	10	144.7	-	-	-	-	83.1	
1200	10	143.8	-	-	-	-	-	73.9

Table 81 (Cont'd)

Tensile Properties of the Ti-679 Alloy Bar at Room Temperature and at the Exposure Temperature after Different Thermal Exposures[a, b, c]

Exposure Conditions Temp. °F	Time Hr	e, % Test Temperature, °F 70	600	800	1000	1100	1150	1200
70	-	14						
600	0.25	-	14					
600	1000	15	14					
800	0.25	-	-	15				
800	100	16	-	14				
800	1000	14	-	14				
1000	0.25	-	-	-	17			
1000	10	14	-	-	15			
1000	100	14	-	-	18			
1000	1000	10	-	-	18			
1100	10	11	-	-	-	22		
1150	10	13	-	-	-	-	27	
1200	10	14	-	-	-	-	-	35

Exposure Conditions Temp. °F	Time Hr	R.A., % Test Temperature, °F 70	600	800	1000	1100	1150	1200
70	-	43						
600	0.25	-	49					
600	1000	44	50					
800	0.25	-	-	49				
800	100	46	-	50				
800	1000	40	-	51				
1000	0.25	-	-	-	56			
1000	10	42	-	-	57			
1000	100	38	-	-	58			
1000	1000	14	-	-	50			
1100	10	21	-	-	-	64		
1150	10	33	-	-	-	-	72	
1200	10	30	-	-	-	-	-	83

a. Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.
b. Section: 1/2 in. x 1-1/8 in.
c. Results are averages of duplicate tests except those for single specimens exposed and tested at 1100, 1150, and 1200° F.

Table 82

Creep Data for the Ti-5Al-5Sn-5Zr Alloy Bar[a, b, c]

Spec. No.	Temp., °F	Stress, ksi	Time to creep deformation, hr 0.05%	0.1%	0.2%	0.5%	2.0%	Min. Creep Rate, % hr^{-1}
5A-110	600	75.0	No creep in 257.1 hr, discontinued.					-
5A-110A	600	90.0	Failed on loading.					-
5A-99	800	59.0	60	350	d	d	d	4.0×10^{-5}
5A-133	800	70.0	23	195	d	d	d	1.7×10^{-4}
5A-104	800	70.0	20	d	d	d	d	8.0×10^{-5}
5A-106	800	70.0	5	29	695	d	d	1.0×10^{-4}
5A-111	800	75.0	6	15	70	d	d	1.0×10^{-4}
5A-127	800	75.0	1	5	270	d	d	1.4×10^{-4}
5A-115	800	77.0	Failed on loading.					-
5A-117	800	80.0	Failed on loading					-
5A-109	900	50.0	0.1	0.3	d	d	d	2.5×10^{-5}
5A-120	900	50.0	70	d	d	d	d	5.0×10^{-5}
5A-113	900	55.0	3	10	44	d	d	2.8×10^{-4}
5A-124	900	60.0	-	-	17	162	d	1.8×10^{-3}
5A-105	900	60.0	2	10	48	215	d	1.7×10^{-3}
5A-116	900	64.0	12	25	33	160	d	3.6×10^{-4}
5A-122	900	68.0	4	10	22	60	430	3.0×10^{-3}
5A-119	900	71.0	-	-	8	19	83	2.6×10^{-2}
5A-123	900	71.0	-	-	5	30	190	7.5×10^{-3}
5A-107	900	73.0	-	1	3	16	88	1.5×10^{-2}
5A-108	1000	18.0	Did not creep in 165.4 hr, discontinued					-
5A-101	1000	22.0	13	45	430	d	d	2.0×10^{-4}
5A-130	1000	30.0	20	100	260	d	d	2.7×10^{-4}
5A-131	1000	30.0	30	160	d	d	d	2.2×10^{-4}
5A-118	1000	36.0	9	25	72	210	915	1.9×10^{-3}
5A-126	1000	38.0	5	12	25	95	694	2.2×10^{-3}
5A-112	1000	41.0	8	14	31	95	565	3.2×10^{-3}
5A-128	1000	43.0	1	2	8	25	186	8.5×10^{-3}
5A-125	1000	46.0	1	2	3	16	150	2.8×10^{-3}
5A-132	1000	55.0	-	-	1	3	17	1.4×10^{-2}

a Heat No. D-8060.

b Section size: 1-1/3 in. x 1/2 in.

c Heat treatment: 1650° F, 2 hr, A.C.

d Denotes that test was discontinued.

Table 83

Creep Data for the Ti-679 Alloy Bar[a, b, c]

Spec. No.	Temp., °F	Stress ksi	Time to creep deformation, hr 0.05%	0.1%	0.2%	0.5%	2.0%	Min. Creep Rate, % hr^{-1}
9A-40	600	110.0	No creep in 128.1 hr, discontinued					—
9A-40A	600	115.0	Failed on loading					—
9A-89	800	70.0	25	215	1000	d	d	8.0×10^{-5}
9A-105	800	85.0	5	20	65	d	d	1.6×10^{-4}
9A-90	800	90.0	5	12	45	630	d	1.4×10^{-4}
9A-85	800	94.0	1	6	35	650	d	2.0×10^{-4}
9A-43	800	94.0	1	2	5	12	d	3.4×10^{-4}
9A-100	800	96.0	1	5	22	260	d	7.6×10^{-4}
9A-52	800	100.0	1	3	6	40	d	1.1×10^{-3}
9A-104	800	100.0	1	2	6	35	d	1.4×10^{-3}
9A-93	900	55.0	5	50	[illegible]50	d	d	1.5×10^{-4}
9A-34	900	60.0	-	3	47	d	d	2.0×10^{-4}
9A-96	900	60.0	5	50	d	d	d	8.0×10^{-5}
9A-54	900	65.0	4	10	38	d	d	3.2×10^{-4}
9A-45	900	72.0	2	3	16	295	d	7.0×10^{-4}
9A-101	900	74.0	4	12	32	d	d	1.6×10^{-4}
9A-44	900	77.0	5	10	26	115	d	1.3×10^{-3}
9A-51	900	79.0	1	2	4	64	500	2.4×10^{-3}
9A-42	900	83.0	0.5	1	2	24	452	2.9×10^{-3}
9A-98	900	85.0	0.5	1	2	13	115	1.2×10^{-2}
9A-102	1000	12.0	20	120	275	950	d	3.6×10^{-4}
9A-36	1000	16.0	10	30	170	370	d	6.0×10^{-4}
9A-103	1000	20.0	35	145	215	415	d	1.4×10^{-3}
9A-86	1000	25.0	22	50	112	230	887	2.2×10^{-3}
9A-94	1000	29.0	5	15	45	132	585	3.4×10^{-3}
9A-50	1000	33.0	18	35	62	120	380	5.6×10^{-3}
9A-92	1000	38.0	6	17	42	150	323	2.5×10^{-3}
9A-88	1000	40.0	1	4	12	65	268	7.4×10^{-3}
9A-31	1000	42.0	3	8	22	90	265	3.0×10^{-3}
9A-32	1000	42.0	1	2	6	75	286	3.0×10^{-3}

a Heat No. D-7274.
b Section size: 1-1/8 in. x 1/2 in.
c Heat treatment: 1650° F, 2 hr, A.C., 930° F, 24 hr, A.C.
d Denotes that test was discontinued.

Table 84

Impact Strength of Ti-5Al-5Sn-5Zr Alloy at Different Temperatures[a, b, c]

Temperature							
70° F		400° F		600° F		800° F	
Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb
5A-206	13.0	5A-207	21.0	5A-208	33.5	5A-209	44.0
5A-210	11.0	5A-211	22.0	5A-212	30.5	5A-213	44.0
5A-214	10.5	5A-215	22.0	5A-216	28.5	5A-217	40.0

a Heat No. D-8060
b Section size: 1-1/8 in. x 1/2 in.
c Heat treatment: 1650° F, 2 hr, A.C.

Table 85

Impact Strength of Ti-679 Alloy Bar at Different Temperatures[a, b, c]

Temperature							
70° F		400° F		600° F		800° F	
Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb
9A-189	14.5	9A-190	20.5	9A-191	23.0	9A-192	33.0
9A-193	12.0	9A-194	16.0	9A-195	19.5	9A-196	24.5
9A-197	16.5	9A-198	14.5	9A-199	30.0	9A-200	37.0
		9A-201	19.5	9A-203	29.0	9A-204	26.0
				9A-202	21.0		

a Heat No. D-7274
b Section size: 1-1/8 in. x 1/2 in.
c Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

Table 84

Impact Strength of Ti-5Al-5Sn-5Zr Alloy at Different Temperatures[a, b, c]

Temperature							
70° F		400° F		600° F		800° F	
Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb
5A-206	13.0	5A-207	21.0	5A-208	33.5	5A-209	44.0
5A-210	11.0	5A-211	22.0	5A-212	30.5	5A-213	44.0
5A-214	10.5	5A-215	22.0	5A-216	28.5	5A-217	40.0

a Heat No. D-8060
b Section size: 1-1/8 in. x 1/2 in.
c Heat treatment: 1650° F, 2 hr, A.C.

Table 85

Impact Strength of Ti-679 Alloy Bar at Different Temperatures[a, b, c]

Temperature							
70° F		400° F		600° F		800° F	
Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb	Spec. No.	Ft-lb
9A-189	14.5	9A-190	20.5	9A-191	23.0	9A-192	33.0
9A-193	12.0	9A-194	16.0	9A-195	19.5	9A-196	24.5
9A-197	16.5	9A-198	14.5	9A-199	30.0	9A-200	37.0
		9A-201	19.5	9A-203	29.0	9A-204	26.0
				9A-202	21.0		

a Heat No. D-7274
b Section size: 1-1/8 in. x 1/2 in.
c Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.

Table 86

Fatigue Data for the Ti-5Al-5Sn-5Zr Alloy Bar[a, b, c]

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[d]
5A-147	70	0.67	1	105.9	63.4	709,600
5A-153	70	0.67	1	100.6	60.2	1,526,200
5A-159	70	0.67	1	95.3	57.0	748,700
5A-189	70	0.67	1	94.0	56.4	2,043,600
5A-177	70	0.67	1	93.6	56.0	15,833,900+
5A-183	70	0.67	1	92.3	55.3	14,056,600+
5A-171	70	0.67	1	91.7	54.9	11,698,300+
5A-165	70	0.67	1	88.2	52.8	11,748,100+
5A-137	70	∞	1	60.0	0	65,900
5A-139	70	∞	1	50.0	0	110,300
5A-156	70	∞	1	45.0	0	357,800
5A-160	70	∞	1	45.0	0	1,407,800
5A-202	70	∞	1	40.0	0	11,580,000+
5A-164	400	0.67	1	95.0	56.8	15,400
5A-180	400	0.67	1	85.0	50.9	38,900
5A-175	400	0.67	1	85.0	50.9	29,500
5A-196	400	0.67	1	80.0	47.9	53,700
5A-168	400	0.67	1	70.0	40.8	240,000
5A-192	400	0.67	1	60.0	35.9	377,000
5A-172	400	0.67	1	55.0	33.0	10,003,000+
5A-201	400	0.67	1	50.0	29.9	10,023,500+
5A-191	400	∞	1	50.0	0	79,800
5A-182	400	∞	1	45.0	0	583,200
5A-138	400	∞	1	40.0	0	345,400
5A-197	400	∞	1	40.0	0	170,500
5A-198	400	∞	1	35.0	0	9,569,000
5A-186	800	0.67	1	70.0	40.8	19,400
5A-183	800	0.67	1	65.0	38.9	85,400
5A-193	800	0.67	1	60.0	35.9	261,200
5A-166	800	0.67	1	55.0	33.0	2,788,000
5A-157	800	0.67	1	50.0	29.9	13,800,100
5A-174	800	∞	1	50.0	0	10,000
5A-149	800	∞	1	45.0	0	20,500
5A-199	800	∞	1	41.0	0	100,100
5A-145	800	∞	1	38.0	0	8,000,600
5A-203	800	∞	1	38.0	0	10,757,000+

Table 86 (Cont'd)

Fatigue Data for the Ti-5Al-5Sn-5Zr Alloy Bar[a, b, c]

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[d]
5A-179	70	0.67	3	40.0	23.9	180,200
5A-162	70	0.67	3	35.0	21.0	213,700
5A-144	70	0.67	3	30.0	18.0	10,145,100+
5A-152	70	0.67	3	30.0	18.0	331,900
5A-154	70	0.67	3	25.0	15.0	13,019,400+
5A-181	70	∞	3	30.0	0	49,300
5A-167	70	∞	3	27.0	0	100,000
5A-146	70	∞	3	25.0	0	172,000
5A-173	70	∞	3	25.0	0	269,700
5A-155	70	∞	3	20.00	0	10,062,600+
5A-151	400	0.67	3	40.0	23.9	213,600
5A-200	400	0.67	3	37.5	22.4	153,500
5A-185	400	0.67	3	37.5	22.4	454,900
5A-150	400	0.67	3	35.0	21.0	415,500
5A-194	400	0.67	3	30.0	18.0	8,217,600+
5A-187	400	∞	3	25.0	0	95,000
5A-148	400	∞	3	22.0	0	267,000
5A-170	400	∞	3	20.0	0	393,500
5A-161	400	∞	3	20.0	0	484,300
5A-143	400	∞	3	15.0	0	9,220,200+
5A-176	800	0.67	3	35.0	21.0	91,000
5A-178	800	0.67	3	35.0	21.0	158,100
5A-190	800	0.67	3	30.0	18.0	120,700
5A-195	800	0.67	3	30.0	18.0	6,201,000
5A-158	800	0.67	3	25.0	15.0	9,667,500+
5A-142	800	∞	3	25.0	0	66,000
5A-134	800	∞	3	20.0	0	39,400
5A-136	800	∞	3	20.0	0	180,200
5A-163	800	∞	3	18.0	0	539,600
5A-167	800	∞	3	15.0	0	9,194,000+

a Heat No. D-8060.
b Section size: 1/2 in. x 1-1/8 in.
c Heat treatment: 1650° F, 2 hr, A.C.
d Plus (+) denotes that test was discontinued.

Table 87

Fatigue Data for the Ti-679 Alloy Bar[a, b, c]

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[d]
9A-148	70	0 67	1	130.6	78.2	45,400
9A-154	70	0.67	1	127.0	76.1	72,300
9A-158	70	0.67	1	119.9	71.8	518,200
9A-164	70	0.67	1	110.8	66.4	74,800
9A-168	70	0.67	1	109.2	65.4	1,587,800
9A-174	70	0.67	1	109.2	65.4	1,107,900
9A-178	70	0.67	1	100.0	59.8	3,506,000
9A-281	70	0.67	1	100.0	59.8	3,220,500
9A-165	70	0.67	1	90.0	58.7	12,176,000+
9A-279	70	∞	1	84.5	0	28,000
0A-273	70	∞	1	82.5	0	34,500
9A-277	70	∞	1	82.5	0	39,800
9A-269	70	∞	1	75.4	0	57,400
9A-140	70	∞	1	68.4	0	313,700
9A-156	70	∞	1	55.0	0	10,029,500+
9A-184	400	0.67	1	100.0	60.0	51,400
9A-149	400	0.67	1	95.0	56.9	129,800
9A-167	400	0.67	1	90.0	53.8	1,541,600
9A-137	400	0.67	1	85.0	51.0	8,650,000
9A-177	400	0.67	1	80.0	48.0	10,001,000+
9A-268	400	∞	1	60.0	0	46,000
9A-139	400	∞	1	60.0	0	65,000
9A-162	400	∞	1	57.0	0	877,300
9A-141	400	∞	1	55.0	0	5,493,300
9A-184	400	∞	1	55.0	0	10,000,000+
9A-169	800	0.67	1	85.0	51.0	14,000
9A-159	800	0.67	1	80.0	48.0	31,200
9A-181	800	0.67	1	80.0	48.0	635,800
9A-274	800	0.67	1	75.0	45.0	473,500
9A-282	800	0.67	1	65.0	38.9	10,207,400
9A-278	800	∞	1	60.0	0	36,100
9A-172	800	∞	1	55.0	0	309,100
9A-157	800	∞	1	50.0	0	374,600
9A-153	800	∞	1	45.0	0	6,871,000
9A-153	800	∞	1	40.0	0	10,000,300+

Table 87 (Cont'd)

Fatigue Data for the Ti-679 Alloy Bar[a, b, c]

Specimen Number	Temp., °F	A	K_t	Max. Stress, ksi	Mean Stress, ksi	Cycles to Fracture[d]
9A-271	70	0.67	3	45.0	26.9	102,600
9A-161	70	0.67	3	42.5	25.4	1,418,100
9A-182	70	0.67	3	42.5	25.4	164,800
9A-151	70	0.67	3	40.0	23.9	3,057,300
9A-180	70	0.67	3	35.0	20.0	10,324,300+
9A-152	70	∞	3	30.0	0	61,000
9A-183	70	∞	3	25.0	0	166,600
9A-163	70	∞	3	25.0	0	149,000
9A-176	70	∞	3	23.0	0	544,500
9A-270	70	∞	3	20.0	0	10,000,000+
9A-275	400	0.67	3	45.0	26.9	99,500
9A-185	400	0.67	3	42.5	25.4	147,100
9A-166	400	0.67	3	40.0	23.9	80,300
9A-147	400	0.67	3	40.0	23.9	305,900
9A-170	400	0.67	3	35.0	20.9	11,188,700+
9A-270	400	∞	3	30.0	0	29,500
9A-175	400	∞	3	30.0	0	90,000
9A-276	400	∞	3	25.0	0	341,700
9A-146	400	∞	3	20.0	0	652,000
9A-179	400	∞	3	20.0	0	10,422,700+
9A-272	800	0.67	3	45.0	27.0	40,800
9A-150	800	0.67	3	40.0	23.9	81,400
9A-160	800	0.67	3	38.0	22.7	44,900
9A-267	800	0.67	3	38.0	22.7	7,048,600
9A-155	800	0.67	3	35.0	20.9	12,718,200+
9A-171	800	∞	3	30.0	0	58,100
9A-143	800	∞	3	25.0	0	88,100
9A-173	800	∞	3	25.0	0	101,600
9A-145	800	∞	3	23.0	0	946,000
9A-280	800	∞	3	20.0	0	10,404,000+

a Heat No. D-7274.
b Section size, 1/2 in. x 1-1/8 in.
c Heat treatment: 1650° F, 2 hr, A.C. + 930° F, 24 hr, A.C.
d Plus (+) denotes that test was discontinued.

Table 88

Data for Calculation of the Stress Intensity Factor for Bar Alloys.

NOTICE

Gross yielding occurred in tests at 400 and 70° F, and to some extent at -110° F, such that the true fracture toughness is not represented by data given in this table.

Alloy	Specimen Number	Temp., ° F	B In.	a In.	w In	$P_{dev-lin}$ [a] lb	K_{nc} [b] ksi $\sqrt{in.}$	σ nom ksi	σ nom / F_{ty}
Ti-5Al-5Sn-5Zr	5A-249	70	.252	.317	1.00	8625	75.6	147.3	1.2
	5A-248	70	.250	.372	1.00	6100	65.7	130.9	1.1
	5A-250	70	.251	.259	1.00	9400	66.0	129.2	1.1
	5A-253	400	.248	.298	1.00	6200	51.8	78.4	1.0
	5A-254	400	.250	.299	1.00	5900	48.6	94.6	1.2
	5A-251	400	.251	.308	1.00	5830	47.9	96.7	1.2
	5A-255	-110	.249	.304	1.00	6860	56.0	–	–
	5A-252	-110	.251	.306	1.00	6950	57.2	–	–
	5A-256	-110	.247	.305	1.00	6480	53.8	–	–
Ti-679	9A-286	70	.250	.362	1.00	5580	55.4	115.1	0.8
	9A-284	70	.251	.269	1.00	8940	62.8	126.1	0.9
	9A-285	[illegible]	.248	.376	1.00	5160	62.1	113.7	0.8
	9A-290	400	.251	.293	1.00	7350	57.7	114.9	1.1
	9A-287	400	.251	.305	1.00	6520	53.6	106.7	1.1
	9A-289	400	.251	.305	1.00	6450	53.1	105.6	1.1
	9A-283	-110	.250	.288	1.00	7190	55.8	–	–
	9A-291	-110	.250	.316	1.00	5550	47.6	–	–
	9A-288	-110	.251	.291	1.00	6600	51.7	–	–

a Load at deviation from linearity in compliance-gage-output vs load curve.

b Stress intensity factor reported as K_{nc}, rather than as K_{Ic}, because pop-in was not observed and calculation was based on load deviation from linearity.

c $\sigma \text{ nom} = \frac{P}{B(W-a)} + \frac{3P\,(W + a - 2D)}{B\,(W - a)^2}$

APPENDIX II

Thermal-Property Test Data

(Tables No. 89-106)

Table 89

The Thermal Conductivity of the Titanium Sheet Alloy,
Ti-5Al-5Sn-5Zr Using the Comparative Rod Apparatus
with 316 Stainless Steel References

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_s Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 1 on Specimen 1								
110	59.1	6.67	100	107	4.30	121	108	6.67
113	57.5	7.73	102	107	4.92	127	108	7.43
351	65.9	39.7	290	117	29.3	417	123	36.0
598	75.8	71.7	468	127	53.4	719	133	69.1
Run 2 on Specimen 1								
112	55.9	8.75	99.8	109	7.90	126	108	7.90
223	[illegible]	19.6	193	112	13.7	254	115	16.0
350	[illegible]	33.0	300	117	22.9	403	112	29.0
Run 3 on Specimen 1								
97	58.9	8.90	82.6	106	6.75	114	103	7.90
619	71.2	77.8	491	127	68.2	745	139	66.9
608	74.6	77.4	482	126	65.6	733	139	66.5
649	76.4	74.7	529	129	61.5	771	141	65.5
765	81.3	85.7	631	134	68.7	906	147	79.5
1032	91.0	83.0	904	147	65.5	1171	161	80.8
946	89.3	80.5	816	143	72.4	1074	156	71.9
953	89.5	84.5	817	143	76.0	1088	156	75.5

Table 90

The Thermal Conductivity of the Titanium Sheet Alloy,
Ti-5Al-5Sn-5Zr-1Mo-1V Using the Comparative Rod Apparatus
with 316 Stainless Steel References

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_s Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 1 on Specimen 1								
110	53.0	6.43	100	107	3.70	121	108	5.80
376	66.0	24.7	337	119	16.4	420	123	23.8
Run 2 on Specimen 1								
139	54.8	14.2	117	108	9.50	163	110	11.9
166	56.5	15.0	143	109	10.7	191	112	12.3
178	57.7	14.9	154	110	11.3	202	112	12.0
288	60.9	34.0	235	114	24.5	340	119	28.7
305	61.7	34.6	241	114	25.2	363	120	29.2
653	74.2	55.2	566	130	46.3	738	139	45.0
644	75.6	48.0	569	130	40.8	720	138	40.4
645	75.8	46.8	571	131	39.2	719	138	40.0
700	77.9	46.0	627	134	39.7	772	141	38.8
709	78.4	46.5	635	134	40.5	781	141	39.0
801	83.0	54.1	716	138	46.7	888	147	48.0
846	86.3	53.0	760	140	47.0	932	149	47.9
938	88.6	53.0	852	145	47.4	1022	153	47.1
1037	93.9	56.5	945	149	50.8	1129	159	52.5
1066	96.0	55.1	976	151	51.0	1156	160	51.0

Table 90 (Continued)

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_3 Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 3 on Specimen 1								
243	58.0	25.0	204	112	18.8	284	117	19.2
284	59.2	21.0	251	115	16.0	318	118	16.0
410	66.9	37.5	352	120	27.0	474	126	34.0
752	79.8	32.7	700	137	29.0	804	142	27.0
802	81.5	40.0	739	139	34.8	866	145	34.0
920	88.1	46.5	848	144	39.3	998	152	43.5
1020	92.0	42.5	953	150	38.0	1090	157	38.5

Table 91

The Thermal Conductivity of the Titanium Sheet Alloy, Ti-6Al-2Sn-4Zr-2Mo Using the Comparative Rod Apparatus with 316 Stainless Steel References

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_s Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 1 on Specimen 1								
189	55.3	14.9	166	111	10.2	214	113	11.9
193	54.9	14.3	171	111	9.50	216	113	11.5
453	70.6	26.5	409	123	22.0	491	127	22.9
786	85.6	29.0	737	139	28.0	835	144	26.4
767	83.3	35.7	710	138	31.8	826	143	31.8
1021	93.6	44.4	946	149	42.8	1095	157	38.8
Run 2 on Specimen 1								
141	56.2	8.47	127	109	5.35	158	110	7.70
327	62.1	22.5	290	117	15.4	366	121	19.8
600	72.2	47.6	516	128	36.0	684	136	41.8
641	73.4	47.8	557	130	36.6	724	138	41.6
891	86.3	55.8	791	142	47.3	986	152	50.6
975	91.0	58.2	872	146	52.1	1073	156	53.2
994	92.1	57.5	894	147	53.2	1089	157	51.6
997	92.4	57.7	896	147	53.9	1093	157	51.4

Table 92

The Thermal Conductivity of the Titanium Bar Alloy,
Ti-5Al-5Sn-5Zr Using the Comparative Rod Apparatus
with 316 Stainless Steel References

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_s Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 1 on Specimen 1								
132	57.2	6.45	118	108	10.1	147	110	10.2
130	57.6	8.22	113	108	11.7	150	110	14.3
276	58.5	33.5	206	113	47.0	349	120	54.0
292	60.0	34.3	219	113	49.3	368	121	56.0
303	60.1	34.8	229	114	51.4	379	121	55.2
511	70.9	38.4	429	124	61.7	595	132	65.5
503	70.4	36.6	426	124	57.4	584	131	63.3
613	72.3	47.2	512	128	75.7	715	138	78.4
753	78.4	51.7	640	134	85.2	866	145	88.6
873	84.2	50.8	761	140	84.3	989	152	91.3
1001	88.1	56.9	871	146	104	1124	158	94.5
Run 2 on Specimen 1								
120	54.6	3.92	111	108	5.97	128	108	5.95
120	56.1	3.82	111	108	6.03	128	108	5.85
368	64.2	23.4	316	118	34.6	421	123	40.0
387	63.9	23.7	333	119	36.4	441	124	38.2
695	74.8	43.2	593	132	73.0	792	142	68.8
711	75.6	43.9	606	132	74.6	809	142	70.4
949	89.0	50.9	832	144	102	1062	155	81.0

Table 93

The Thermal Conductivity of the Titanium Bar Alloy, Ti-679, Using the Comparative Rod Apparatus with 316 Stainless Steel References

Mean Temperature of Specimen °F	Thermal Conductivity of Specimen K_S Btu/hr/ft²/°F/in.	ΔT through Specimen °F	Mean Temperature of Lower Reference °F	Thermal Conductivity of Lower Reference K_1 Btu/hr/ft²/°F/in.	ΔT through Lower Reference ΔT_1 °F	Mean Temperature of Upper Reference °F	Thermal Conductivity of Upper Reference K_2 Btu/hr/ft²/°F/in.	ΔT through Upper Reference ΔT_2 °F
Run 1 on Specimen 1								
108	58.4	4.48	99.0	107	6.72	118	108	7.90
229	60.9	23.1	181	111	32.3	283	116	41.7
444	68.9	32.1	371	121	54.3	516	128	52.5
587	74.8	41.2	492	127	71.1	682	136	69.7
622	76.0	41.7	527	128	72.2	718	138	70.6
634	76.5	41.1	539	129	71.6	728	139	69.3
766	82.8	42.0	668	136	74.0	865	145	[illegible]
957	87.2	58.3	821	143	106	1088	156	98.0
1031	89.2	63.7	882	146	116	1174	161	107
Run 2 on Specimen 1								
1037	88.0	63.7	887	146	116	1174	161	103
685	75.9	43.8	583	131	75.4	784	141	71.2
442	67.8	36.0	362	120	57.4	526	128	60.4
438	67.4	35.8	360	120	57.0	520	128	59.5
291	62.7	17.2	252	115	28.9	339	119	26.5
185	60.2	12.2	157	110	20.0	213	113	19.5
133	58.0	6.60	119	108	10.6	149	110	10.6
94	57.2	3.30	86.4	106	4.89	102	107	5.67

Table 94

The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Sheet Form Parallel to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 2 on Specimen 1					
75.0	7:55	0.0	0.00	0.0	0.0
218	8:50	1.6	0.51	0.04	0.55
266	9:27	2.2	0.70	0.06	0.76
309	9:47	2.9	0.92	0.07	0.99
404	10:30	4.4	1.40	0.10	1.50
518	11:20	6.1	1.94	0.14	2.08
622	12:20	7.9	2.51	0.17	2.68
710	1:13	9.2	2.92	0.20	3.12
735	1:56	9.6	3.05	0.20	3.25
842	3:00	11.4	3.62	0.24	3.86
928	3:37	12.8	4.08	0.26	4.34
999	4:25	14.1	4.48	0.28	4.76
1013	4:50	14.4	4.57	0.29	4.86
70.0	10:50am	0.0	0.00	0.00	0.0

Note: Initial length of specimen and end caps = 3.150 in.
Final length of specimen and end caps = 3.150 in.
Specimen length = 3.003 in.

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 3 on Specimen 1					
78.0	9:58	0.0	0.00	0.0	0.0
231	10:20	1.8	0.57	0.05	0.62
374	10:40	4.2	1.34	0.09	1.43
505	11:05	6.4	2.04	0.13	2.17
565	11:20	7.4	2.35	0.15	2.50
590	11:25	7.6	2.42	0.16	2.58
799	12:00	11.1	3.53	0.22	3.75
924	1:15	13.5	4.29	0.26	4.55
999	1:35	14.9	4.74	0.28	5.02
426	2:35	4.6	1.47	0.11	1.57
284	3:10	2.6	0.83	0.06	0.89
72.7	8:00	0.0	0.00	0.0	0.0

Note: Initial length of specimen and end caps = 3.143 inch
Final length of specimen and end caps = 3.143 inch
Specimen length = 3.003 inch

Table 95

The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Sheet Form Transverse to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 1 on Specimen 1					
76.0	10:30	0.0	0.00	0.0	0.0
160	11:00	1.0	0.32	0.03	0.35
217	11:15	1.9	0.61	0.04	0.65
240	11:30	2.2	0.70	0.05	0.75
415	12:30	4.7	1.50	0.11	1.61
600	1:45	7.6	2.43	0.16	2.59
766	2:35	10.2	3.26	0.21	3.47
919	3:10	12.4	3.96	0.26	4.22
1012	4:05	14.0	4.47	0.29	4.76
1021	4:15	14.1	4.51	0.29	4.80
1026	4:15	14.1	4.51	0.29	4.80
930	4:55	12.6	4.03	0.26	4.29
777	5:15	10.0	3.20	0.22	3.42
650	5:30	7.5	2.52	0.18	2.70
570	5:40	6.4	2.04	0.15	2.19
522	5:48	5.6	1.79	0.14	1.93
80.7	7:50am	-0.8	-0.26	0.0	-0.26

Note: Initial length of specimen and end caps = 3.128 in.
Final length of specimen and end caps = 3.128 in.
Specimen length = 2.975 in.

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 2 on Specimen 1					
80.2	2:35	0.0	0.00	0.0	0.0
208	3:00	1.7	0.54	0.04	0.58
408	3:30	4.7	1.51	0.10	1.61
585	3:45	7.8	2.50	0.16	2.66
810	4:05	11.5	3.68	0.26	3.94
1005	4:25	15.0	4.80	0.29	5.09
447	5:15	5.3	1.70	0.11	1.81
370	5:35	4.2	1.34	0.09	1.43
72.7	8:00	0.0	0.00	0.0	0.0

Note: Initial length of specimen and end caps = 3.122 inch
Final length of specimen and end caps = 3.122 inch
Specimen length = 2.975 inch

Table 96

The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr-1Mo-1V in Sheet Form Parallel to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 1 on Specimen 1					
78.0	10:30	0.0	0.0	0.0	0.0
200	11:25	1.4	0.44	0.04	0.48
426	12:20	4.8	1.52	0.11	1.63
580	12:55	7.4	2.35	0.16	2.51
802	1:25	11.0	3.49	0.22	3.71
1004	1:55	14.3	4.54	0.28	4.82
676	2:25	8.4	2.67	0.18	2.86
385	3:05	3.6	1.14	0.10	1.24
75.2	4:20	-0.6	-0.19	0.0	-0.19
Note: Initial length of specimen and end caps = 3.149 in. Final length of specimen and end caps = 3.149 in. Specimen length = 2.999 in.					
Run 2 on Specimen 1					
77.8	12:25	0.0	0.0	0.0	0.0
216	1:05	1.9	0.60	0.04	0.64
414	1:35	4.9	1.56	0.10	1.66
609	1:50	8.2	2.61	0.17	2.78
795	2:10	11.5	3.66	0.22	3.88
1010	2:40	15.2	4.84	0.28	5.12
834	2:55	12.1	3.85	0.23	4.08
717	3:05	9.9	3.15	0.20	3.35
484	3:55	5.9	1.88	0.13	2.01
77.0	8:00	0.2	0.06	0.0	0.06
Note: Initial length of specimen and end caps = 3.143 inch Final length of specimen and end caps = 3.143 inch Specimen length = 2.999 inch					

Table 97

The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr-1 Mo-1V in Sheet Form Transverse to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 1 on Specimen 1					
75.5	8:00	0.0	0.0	0.0	0.0
233	8:35	2.2	0.70	0.05	0.75
421	9:05	4.9	1.56	0.11	1.67
503	9:28	6.2	1.98	0.14	2.12
576	9:45	7.3	2.33	0.16	2.49
704	10:15	9.4	3.00	0.20	3.20
847	10:40	11.7	3.73	0.24	3.97
1007	11:10	14.6	4.65	0.28	4.93
789	11:25	10.6	3.38	0.22	3.60
365	12:20	3.5	1.12	0.09	1.21
77.0	8:00	-0.5	-0.16	0.0	-0.16
Note: Initial length of specimen and end caps = 3.137 in. Final length of specimen and end caps = 3.137 in. Specimen length = 3.001 in.					
Run 2 on Specimen 1					
78.5	9:25	0.0	0.0	0.0	0.0
206	9:55	1.7	0.54	0.04	0.58
406	10:20	4.7	1.49	0.10	1.59
578	10:45	7.6	2.42	0.16	2.58
716	11:00	10.1	3.21	0.20	3.41
812	11:15	11.7	3.72	0.23	3.95
1007	12:40	15.2	4.83	0.28	5.11
714	1:05	9.7	3.08	0.20	3.28
493	1:30	6.0	1.91	0.13	2.04
325	2:05	3.6	1.14	0.08	1.22
78.0	8:00	0.2	0.06	0.0	0.06
Note: Initial length of specimen and end caps = 3.144 inch Final length of specimen and end caps = 3.144 inch Specimen length = 3.001 inch					

Table 98

The Thermal Expansion of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form Parallel to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 2 on Specimen 1					
80.5	10:00	0.0	0.0	0.0	0.0
239	10:35	1.9	0.60	0.05	0.65
91.5	1:00	0.0	0.0	0.0	0.0
222	1:38	1.8	0.57	0.04	0.61
421	2:10	4.8	1.52	0.11	1.63
597	2:35	7.4	2.35	0.16	2.51
812	3:05	11.9	3.77	0.23	4.00
1010	3:55	14.3	4.54	0.28	4.82
672	4:20	8.4	2.66	0.19	2.85
483	4:40	5.3	1.68	0.13	1.81
77.5	8:00	0.0	0.0	0.0	0.0

Note: Initial length of specimen and end caps = 3.153 in.
Final length of specimen and end caps = 3.153 in.
Specimen length = 3.001 in

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 3 on Specimen 1					
78.0	9:45	0.0	0.0	0.0	0.0
224	10:20	1.8	0.57	0.05	0.62
410	10:50	4.7	1.49	0.10	1.59
590	11:15	7.6	2.41	0.16	2.57
808	11:45	11.4	3.62	0.23	3.85
1009	12:20	15.1	4.80	0.28	5.08
537	1:05	6.9	2.19	0.14	2.33
78.0	7:50	0.3	0.10	0.0	0.10

Note: Initial length of specimen and end caps = 3.148 inch
Final length of specimen and end caps = 3.148 inch
Specimen length = 3.001 inch

Table 90

The Thermal Expansion of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form Transverse to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 1 on Specimen 2					
77.5	8:00	0.0	0.0	0.0	0.0
244	8:35	2.2	0.70	0.05	0.75
404	9:10	4.7	1.50	0.10	1.60
610	9:47	8.0	2.55	0.17	2.72
793	10:10	10.4	3.31	0.22	3.53
1001	11:16	13.7	4.37	0.28	4.65
781	11:35	10.1	3.22	0.22	3.44
337	12:37	3.0	0.96	0.08	1.04
90.3	1:20	0.0	0.0	0.0	0.0
Note: Initial length of specimen and end caps = 3.137 in. Final length of specimen and end caps = 3.137 in. Specimen length = 3.001 inch					
Run 2 on Specimen 1					
80.0	10:25	0.0	0.0	0.0	0.0
217	10:55	1.7	0.54	0.04	0.58
410	11:15	4.8	1.53	0.10	1.63
581	11:35	7.6	2.42	0.16	2.58
796	12:25	11.1	3.53	0.22	3.75
1004	1:00	14.7	4.67	0.28	4.95
686	1:25	9.5	3.02	0.19	3.21
374	2:00	5.0	1.59	0.09	1.68
77.5	8:00	-0.2	0.06	0.0	0.06
Note: Initial length of specimen and end caps = 3.144 inch Final length of specimen and end caps = 3.144 inch Specimen length = 3.001 inch					

Table 100

The Thermal Expansion of the Titanium Alloy Ti-5Al-5Sn-5Zr in Bar Form Parallel to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 1 on Specimen 1					
83.5	1:05	0.0	0.0	0.0	0.0
265	2:15	2.0	0.67	0.06	0.73
330	2:30	3.0	1.00	0.08	1.08
388	3:00	4.0	1.33	0.10	1.42
436	3:07	4.7	1.57	0.11	1.68
530	3:25	6.1	2.03	0.14	2.17
593	3:35	7.7	2.37	0.16	2.53
649	3:45	8.0	2.67	0.18	2.85
736	3:57	9.5	3.17	0.20	3.37
809	4:08	10.6	3.53	0.22	3.75
852	4:14	11.2	3.73	0.24	3.97
394	4:22	11.9	3.96	0.25	4.21
938	4:28	12.7	4.23	0.26	4.49
1009	4:35	14.0	4.66	0.29	4.95
305	4:50	3.5	1.17	0.07	1.24
278	4:51	2.9	0.97	0.06	1.03
91.0	5:25	0.2	0.07	0.01	0.08
71.8	6:15	0.0	0.0	0.0	0.0
Note: Initial specimen length = 3.001 inch. Final specimen length = 3.001 inch.					
Run 2 on Specimen 1					
76.0	1:20	0.0	0.0	0.0	0.0
147	1:52	0.9	0.30	0.02	0.32
189	2:05	1.5	0.50	0.04	0.54
286	2:30	2.9	0.97	0.06	1.03
404	3:00	4.5	1.50	0.10	1.60
503	3:45	6.1	2.03	0.13	2.16
511	3:50	6.2	2.06	0.13	2.19
70	10:20	-0.1	-0.03	0.0	-0.03
70	8:40	0.0	0.0	0.0	0.0
144	9:05	0.7	0.23	0.02	0.25
187	9:40	1.5	0.50	0.04	0.54
258	10:00	2.5	0.83	0.06	0.89
398	12:20	4.4	1.47	0.10	1.57
577	10:35	7.4	2.47	0.15	2.62
698	10:50	9.3	3.10	0.19	3.29
790	11:08	10.6	3.53	0.22	3.75
910	11:23	12.5	4.17	0.26	4.43
974	11:38	13.7	4.57	0.28	4.85
1004	11:44	14.1	4.70	0.28	4.98
772	12:00	10.2	3.40	0.21	3.61
638	12:20	8.0	2.67	0.17	2.84
502	12:35	5.6	1.87	0.13	2.00
458	12:55	5.1	1.70	0.12	1.82
85	3:[illegible]5	0.0	0.0	0.0	0.0
Note: Initial specimen length = 3.001 inch. Final specimen length = 3.001 inch					

Table 101

The Thermal Expansion of the Titanium Alloy Ti-679
in Bar Form Parallel to the Rolling Direction Using a Quartz Dilatometer

Temperature °F	Time	Observed Total Elongation 10^{-3} in.	Observed Unit Elongation 10^{-3} in./in.	Unit Elongation Correction for Dilatometer Motion 10^{-3} in./in.	Corrected Specimen Unit Elongation 10^{-3} in./in.
Run 2 on Specimen 1					
74.5	3:45	0.0	0.0	0.0	0.0
148	4:07	0.9	0.30	0.02	0.32
210	4:25	1.9	0.63	0.04	0.67
296	4:47	3.1	1.03	0.07	1.10
408	5:12	4.7	1.57	0.10	1.67
503	5:40	6.1	2.03	0.13	2.16
593	6:00	7.6	2.53	0.16	2.69
704	6:35	9.5	3.17	0.20	3.37
815	6:50	11.3	3.76	0.23	3.99
890	7:10	12.5	4.16	0.25	4.41
998	7:25	14.5	4.83	0.28	5.11
72	8:00	0.2	0.07	0.0	0.07
Note: Initial specimen length = 3.001 in. Final specimen length = 3.001 in.					
Run 3 on Specimen 1					
80.3	12:20	0.0	0.0	0.0	0.0
212	1:10	1.8	0.60	0.04	0.64
406	1:35	4.8	1.60	0.10	1.70
599	1:55	7.9	2.63	0.16	2.79
797	2:15	11.4	3.80	0.22	4.02
998	2:40	14.8	4.93	0.28	5.21
774	3:00	10.8	3.60	0.22	3.82
465	3:30	5.9	1.97	0.13	2.10
312	4:10	3.2	1.07	0.07	1.14
78.0	8:00	0.2	0.06	0.0	0.06
Note: Initial specimen length = 3.001 inch Final specimen length = 3.001 inch					

Table 102

The Enthalpy of the Titanium Alloy Ti-679
in Bar Form Using the Adiabatic Calorimeter

Run No.	Initial Cup Temp. °F	Final Cup Temp. °F	Change in Cup Temp. °F	Initial Sample Temp. °F	Time to Temp. Min	Initial Wt. of Sample gm	Final Wt. of Sample gm	Enthalpy $h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85°F Reference Btu/lb
Specimen 1									
1	77.13	77.45	0.32	115	10	9.7059	9.7059	3.97	3.17
2	78.04	79.13	1.09	194	25	9.7059	9.7057	13.5	12.8
4	81.69	85.61	3.92	477	35	9.7057	9.7054	48.6	48.7
5	91.35	96.50	5.15	627	31	9.7054	9.7054	63.9	65.3
6	80.26	87.22	6.96	766	45	9.7054	9.7054	86.3	86.0
7	82.74	90.74	8.00	875	60	9.7054	9.7054	99.2	100
8	87.61	96.87	9.26	1012	56	9.7054	9.7054	115	116
Specimen 2									
9	79.63	83.41	3.78	461	49	9.9125	9.9125	45.9	45.9
10	81.74	86.95	5.21	602	63	9.9125	9.9125	63.3	63.5
11	85.35	94.91	9.56	977	52	9.9125	9.9125	116	117
12	78.91	86.87	7.96	857	52	9.9127	9.9130	96.7	96.9

Note: Each degree of temperature change of the cup represents a specimen enthalpy above the final cup temperature of 0.2654 Btu per pound.

Table 103

The Enthalpy of the Titanium Alloy Ti-5Al-5Sn-5Zr
in Bar Form Using the Adiabatic Calorimeter

Run No.	Initial Cup Temp. °F	Final Cup Temp. °F	Change in Cup Temp. °F	Initial Sample Temp. °F	Time to Temp. Min	Initial Wt. of Sample gm	Final Wt. of Sample gm	Enthalpy $h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85°F Reference Btu/lb
Specimen 1									
1	76.22	76.69	0.47	133	18	8.3026	8.3030	6.81	5.80
2	76.82	78.04	1.22	212	20	8.3030	8.3022	17.7	16.8
3	80.35	82.56	2.21	336	33	8.3022	8.3022	32.0	31.7
4	78.17	81.82	3.65	478	42	8.3022	8.3010	52.9	52.5
5	86.87	91.69	4.83	636	40	8.3010	8.3010	69.9	70.8
6	78.82	85.09	6.27	764	52	8.3010	8.3010	90.9	90.9
7	82.35	89.35	7.00	858	57	8.3010	8.3010	102	102
8	79.50	88.00	8.50	995	82	8.3010	8.3015	123	124
9	84.65	93.26	8.61	1008	69	8.3015	8.3015	125	126

Note: Each degree of temperature change of the cup represents a specimen enthalpy above the final cup temperature of 0.2654 Btu per pound.

Table 104

The Enthalpy of the Titanium Alloy Ti-5Al-5Sn-5Zr in Sheet Form Using the Adiabatic Calorimeter

Run No.	Initial Cup Temp. °F	Final Cup Temp. °F	Change in Cup Temp. °F	Initial Sample Temp. °F	Time to Temp. Min	Initial Wt. of Sample gm	Final Wt. of Sample gm	Enthalpy $h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85°F Reference Btu/lb
Specimen 1									
1	77.45	77.50	0.05	110	20	1.6555	1.6553	3.64	2.80
2	76.43	76.78	0.35	245	43	1.6553	1.6553	25.4	24.2
3	80.00	80.43	0.43	316	30	1.6553	1.6555	31.3	30.6
4	77.32	78.04	0.72	472	48	1.6555	1.6555	52.4	51.4
5	86.82	87.74	0.92	627	30	1.6555	1.6555	66.9	67.2
6	77.50	78.82	1.32	765	49	1.6555	1.6555	96.0	95.1
7	81.13	82.65	1.52	893	32	1.6555	1.6553	110	110
8	77.63	79.43	1.80	999	51	1.6553	1.6555	131	130
Specimen 2									
9	79.00	79.63	0.63	259	37	2.9690	2.9690	25.5	24.8
10	83.41	85.48	2.07	962	64	2.1412	2.1412	116	116

Note: Each degree of temperature change of the cup represents a specimen enthalpy above the final cup temperature of 0.2654 Btu per pound.

Table 105

The Enthalpy of the Titanium Alloy Ti-5Al-5Sn-5Zr-1Mo-1V
in Sheet Form using the Adiabatic Calorimeter

Run No.	Initial Cup Temp. °F	Final Cup Temp. °F	Change in Cup Temp. °F	Initial Sample Temp. °F	Time to Temp. Min	Initial Wt. of Sample gm	Final Wt. of Sample gm	Enthalpy $h = \frac{K}{W_s}(t_2 - t_1)$ Btu/lb	Enthalpy Above 85°F Reference Btu/lb
Specimen 1									
1	75.56	75.78	0.22	165	35	1.8233	1.8232	14.5	13.0
2	75.82	76.13	0.31	215	48	1.8232	1.8231	20.5	19.2
3	79.04	79.59	0.55	312	80	1.8231	1.8231	36.3	34.2
4	84.22	85.00	0.78	474	42	1.8231	1.8231	51.5	51.5
5	85.43	86.43	1.00	619	52	1.8231	1.8227	66.0	66.2
6	85.69	87.04	1.35	766	41	1.8227	1.8227	89.2	89.4
7	77.86	79.54	1.68	873	55	1.8227	1.8230	111	110
8	88.74	90.56	1.82	1003	48	1.8230	1.8230	121	121
Specimen 2									
9	77.32	78.00	0.68	248	45	3.1738	3.1738	25.8	24.7
10	83.18	84.91	2.17	586	61	3.1738	3.1738	65.6	65.6
11	80.56	77.41	3.15	950	84	3.1738	3.1738	119	119
Specimen 3									
12	85.44	87.90	2.46	550	46	4.9969	4.9969	59.3	59.6

Note: Each degree of temperature change of the cup represents a specimen enthalpy above the final cup temperature of 0.2654 Btu per pound.

Table 106

The Enthalpy of the Titanium Alloy Ti-6Al-2Sn-4Zr-2Mo in Sheet Form Using the Adiabatic Calorimeter

Run No.	Initial Cup Temp. °F	Final Cup Temp. °F	Change in Cup Temp. °F	Initial Sample Temp. °F	Time to Temp. Min	Initial Wt. of Sample gm	Final Wt. of Sample gm	Enthalpy $h = \frac{K}{W_s} \cdot (t_2 - t_1)$ Btu/lb	Enthalpy Above 85°F Reference Btu/lb
Specimen 1									
2	76.13	76.43	0.30	203	19	1.7396	1.7396	20.8	19.4
3	79.54	80.04	0.50	337	39	1.7396	1.7394	34.6	33.9
4	84.91	85.61	0.70	457	24	1.7394	1.7394	48.4	48.4
5	85.95	86.95	1.00	646	65	1.7394	1.7388	69.2	69.5
6	86.87	88.17	1.30	771	24	1.7388	1.7394	90.0	90.4
7	79.54	81.17	1.63	880	44	1.7394	1.7396	113	112
8	75.56	77.50	1.94	994	96	1.7396	1.7396	134	133
Specimen 2									
9	78.04	78.87	0.83	189	38	7.1800	7.1800	13.9	13.0
10	79.23	83.05	3.82	565	49	7.1800	7.1800	64.0	63.8
Specimen 3									
12	74.09	80.06	5.97	796	50	7.1802	7.1798	100	99.4
13	77.71	84.81	7.10	936	33	7.1798	7.1798	119	119

Note: Each degree of temperature change of the cup represents a specimen enthalpy above the final cup temperature of 0.2654 Btu per pound.

APPENDIX III

Summary of Property Evaluations

(Tables No. 107-109)

Table 107

Summary of Evaluations for Ti-5Al-5Sn-5Zr-1Mo-1V, Ti-5Al-5Sn-5Zr, and Ti-6Al-2Sn-4Zr-2Mo Alloys in Sheet Form

Test	Temperature and Specimen Quantity						Tests/Alloy	Total Tests
	-110° F	RT	400° F	600° F	800° F	1000° F		
Tension		10L-10T	10L-10T	10L-10T	10L-10T	10L-10T	200[a]	600
Compression		5L- 5T	5L- 5T	5L- 5T	5L- 5T	5L- 5T	50	150
Shear (Single)		5L- 5T	5L- 5T	5L- 5T	5L- 5T	5L- 5T	50	150
Bearing e/D = 1.5		3L- 3T	3L- 3T	3L- 3T	3L- 3T	3L- 3T	30	90
Bearing e/D = 2.0		3L- 3T	3L- 3T	3L- 3T	3L- 3T	3L- 3T	30	90
Exposure-Tensile[b]								
1000 hr				6L	6L	3L	18	54
100 hr					6L	6L	12	36
10 hr						4L	4	12
Exposure-Shear[b]		Same as Exposure-Tensile tests					34	102
Over-Exposure-Tensile								
10 hr		3L at each temperature of 1100, 1150, and 1200 F[c]					9	27
Creep				10L	10L	10L	30	90
Axial Fatigue								
A = 1.0		10L	10L		10L		30	90
A = 0.67		10L	10L		10L		30	90
Dynamic Modulus		1L- 1T	for all five temperatures				2	6
Fracture Toughness	3L-3T	3L- 3T	3L- 3T				18	54
Stress Corrosion		Three specimens exposed under 9 temperature-stress conditions					36	108

L - Longitudinal direction
T - Transverse direction
a - Two heats per alloy tested in tension
b - Duplicate specimens tested at room temperature and the exposure temperature after the exposure period
c - One specimen per group tested at the exposure temperature

Table 108

Summary of Evaluations for Ti-5Al-5Sn-5Zr and Ti-679 Alloys in Bar Form

Test	Temperature and Specimen Quantity						Tests/Alloy	Total Tests
	-110° F	RT	400° F	600° F	800° F	1000° F		
Tension		10L	10L	10L	10L	10L	100[a]	200
Compression		5L	5L	5L	5L	5L	25	50
Shear (Double)		5L	5L	5L	5L	5L	25	50
Exposure-Tensile[b]								
1000 hr				6L	6L	6L	18	36
100 hr					4L	4L	8	16
10 hr						4L	4	8
Over-Exposure-Tensile								
10 hr		3L at each temperature of 1100, 1150, and 1200° F[c]					9	18
Creep				10L	10L	10L	30	60
Axial Fatigue								
A = ∞		10L	10L		10L		30	60
A = 0.67		10L	10L		10L		30	60
Dynamic Modulus		1L for all five temperatures					1	2
Impact		3L	3L	3L	3L		12	24
Fracture Toughness	3L	3L	3L				9	18

L - Longitudinal direction
a - Two heats per alloy tested in tension
b - Duplicate specimens tested at room temperature and the exposure temperature after the exposure period
c - One specimen per group tested at the exposure temperature

Table 109

Summary of Thermal Conductivity, Thermal Expansion, and Specific Heat Determinations

Alloy	Form	Temperature Range - ° F	Total Tests for Each Property[a]
Ti-5Al-5Sn-5Zr	Sheet and Bar	RT to 1000	6
Ti-5Al-5Sn-5Zr-1Mo-1V	Sheet	RT to 1000	3
Ti-6Al-2Sn-4Zr-2Mo	Sheet	RT to 1000	3
Ti-679	Bar	RT to 1000	3

a Thermal expansion determined for both transverse and longitudinal orientations for the alloys in sheet form

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	Air Force Materials Laboratory Research & Technology Division Air Force Systems Command Wright-Patterson AFB, Ohio

13. ABSTRACT

The purpose of this program was to obtain preliminary mechanical- and thermal-property design data on some of the newer titanium alloys. Three sheet alloys (Ti-5Al-5Sn-5Zr, Ti-5Al-5Sn-5Zr-1Mo-1V, and Ti-6Al-2Sn-4Zr-2Mo) and two bar alloys (Ti-5Al-5Sn-5Zr and Ti-679) were studied. Tests were performed to obtain data on the following properties: tensile, compression, bearing, shear, thermal exposure, creep, axial fatigue, fracture toughness, stress corrosion, impact, dynamic modulus, thermal conductivity, thermal expansion, and specific heat. In general these properties were determined over the temperature range from 70 to 1000°F, with most properties being measured at 70, 400, 600, 800 and 1000°F.

Results of the tests show that the new Ti-6Al-2Sn-4Zr-2Mo sheet alloy has well-balanced properties; with short-time strength at all temperatures comparable to or higher than those of other alpha-beta alloys and higher long-time strength (creep) than other alpha-beta alloys to which it was compared. The Ti-679 bar alloy also exhibited generally high strength over the temperature range at which properties were studied.

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